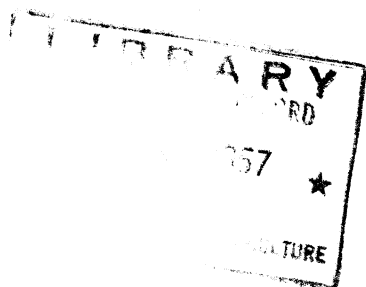


curve  
1984 Te

# Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments



Technical Bulletin  
No. 1164

UNITED STATES DEPARTMENT OF AGRICULTURE  
in cooperation with State Agricultural Experiment Stations

\* Nitrogen and Carbon Changes  
in Great Plains Soils as  
Influenced by Cropping  
and Soil Treatments

by H. J. Haas and C. E. Evans, soil scientists,  
Soil and Water Conservation Research Division,  
Agricultural Research Service; and E. F. Miles,  
former physicist, Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

In cooperation with the Agricultural Experiment Stations of North Dakota, South Dakota, Montana, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, and Texas

# CONTENTS

	Page
Description of experimental areas.....	2
Locations.....	2
Climate.....	5
Collection and preparation of samples.....	6
Total nitrogen and carbon study.....	6
Soluble-nitrogen study.....	7
Analytical procedures.....	8
Relationship between soil nitrogen and particle size.....	8
Comparison of nitrogen and carbon content of virgin and cropped soils.....	11
Rate of decline in soil nitrogen with years of cropping.....	15
Influence of specific cropping practices on the total nitrogen and carbon content and the carbon/nitrogen ratio of the soil.....	16
Effects of small grains.....	17
Continuous cropping versus fallow for small grains and row crops.....	18
Barnyard manure versus no manure.....	22
Effects of green-manure crops on soil nitrogen and carbon.....	24
Effects of grass and alfalfa on nitrogen and carbon changes.....	27
Soil nitrogen in relation to nitrification rate and uptake of nitrogen by plants..	30
Laboratory studies.....	30
Relationship of total nitrogen in the soil and nitrate production during a 6- week incubation period.....	31
Relationship of total nitrogen in the soil and nitrate-nitrogen production during 6, 12, 18, and 24 weeks of incubation.....	33
Nitrate-nitrogen production from cropped soils as compared with that from virgin sod.....	36
Effects of previous crop or fallow on nitrate production.....	37
Field studies.....	38
Nitrogen uptake by wheat in relation to nitrogen content of soil.....	38
Effects of barnyard manure on nitrogen content and yield of wheat during one season at several locations.....	39
Effects of soil-nitrogen changes on crop yields.....	42
Summary.....	53
Literature cited.....	55
Appendix tables.....	58

# Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments<sup>1</sup>

By H. J. Haas and C. E. Evans, *soil scientists*, Soil and Water Conservation Research Division, Agricultural Research Service; and E. F. Miles, *\* former physicist*, Agricultural Research Service.

Numerous investigations have shown that there has been a sharp decline in nitrogen and carbon content of the soil after the land has been put under cultivation. The majority of these investigations were conducted in the more humid regions. A few such studies, however, were carried on in the Great Plains. In some instances, these studies showed nitrogen and carbon losses as high as those in the more humid regions.

Russel (37)<sup>2</sup> reported that the soils studied in Nebraska had lost from 25 to 30 percent of their organic matter after 30 years of cropping. Gainey and coworkers (18), working with soils from experiment stations in western Kansas, showed that large losses of nitrogen had resulted from cropping. Myers and coworkers (33) showed that these same soils continued to decline with further cropping. Newton and coworkers (34) reported upon analyses of soils in Alberta, Saskatchewan, and Manitoba, Canada. The average period of cultivation was a little over 22 years. Nitrogen lost, compared with that lost from virgin sod, ranged from 0 to 40 percent. The average loss in soil nitrogen was 18 percent for brown, dark brown, and black soils, and 30 percent for gray soils. Volkerding and Stoa (47) studied the changes in soil nitrogen under rotation systems of farming at Fargo, N. Dak., and found that, over a 33-year period, soil nitrogen had been reduced 20 percent. Chang (9), working in the Tucumcari region in northeastern New Mexico, reported that surface soils which had been cropped for an average of 22 years lost 31 percent nitrogen and 44 percent organic matter.

In contrast to these results, Stewart (43) and Stewart and Hirst (44) reported on early work done in Utah, where no decline in soil nitrogen occurred when wheat had been grown for periods of 10 to 50 years. They stated that the deep-rooted wheat plants were able to secure a portion of their nitrogen from the lower depths of soil. They also stated that the plowing under of the straw and stubble tended to maintain the nitrogen content of cultivated surface soils.

As large losses of nitrogen and carbon from dryland soils in the Great Plains were measured at several locations, it was decided in 1947 to make a comprehensive study of the problem.<sup>3</sup>

\*Mr. Miles is deceased. He was a member of the former Bureau of Plant Industry, Soils, and Agricultural Engineering.

<sup>1</sup> Submitted for publication December 1956.

<sup>2</sup> Italic numbers in parentheses refer to Literature Cited, p. 55.

<sup>3</sup> The authors are indebted to Lyle T. Alexander, Chief, Soil Survey Laboratories, Soil Conservation Service, and O. R. Mathews (retired), former agronomist, Soil and Water Conservation Research Branch, Agricultural Research Service, for assistance and guidance in planning and conducting this study.

The purposes of the study were: To determine the effect of cropping on the total nitrogen and carbon contents of various dryland soils; to evaluate the relationship of total nitrogen in the soil to the capacity of that soil to produce nitrate-nitrogen; and to show the influence of the soil-nitrogen changes on crop yields.

The majority of the soil and plant samples reported upon were collected from selected experimental stations located throughout the Great Plains. Soil samples were also collected from privately owned farmland in North Dakota.

## Description of Experimental Areas

### Locations

In the early part of the 20th century, experimental stations were established at various locations throughout the Great Plains to study the effects of different rotations and tillage practices on crop production under dryland conditions. Where practicable, cropping treatments were similar at all stations and were in effect for a period of 30 to 40 years. These stations provided excellent opportunities to study nitrogen problems as influenced by different cropping treatments over a wide range of soil and climatic conditions. However, there were two rather serious limitations; the lack of replication of rotations at each station; and the fact that, in most instances, no soil samples were taken at the time the rotations were established.

In 1947, a survey<sup>4</sup> of these experimental stations was made to aid in selecting the stations and rotations from which samples were to be collected for the total-nitrogen and organic-carbon study. Each experimental field was surveyed to determine the soil type or types, uniformity, degree of erosion, and any other factors which would influence the selection of the plots for sampling.

At a given station, only those rotations were selected which were comparable as far as the above factors were concerned. An attempt was made to include rotations which were uniform for all stations. This was not always possible because of differences between stations in adaptable crops, and also because some rotations were so located as not to be comparable with other rotations.

The following list shows the designations and locations of the 17 stations selected. Throughout this bulletin, in both text passages and tables, the place name alone is generally used to designate the experimental stations.

<i>Experimental station</i>	<i>Location</i>
United States Northern Great Plains Field Station.....	Mandan, N. Dak.
Dickinson Substation.....	Dickinson, N. Dak.
North Montana Branch Station.....	Havre, Mont.
Central Montana Branch Station.....	Moccasin, Mont.
Huntley Branch Station.....	Huntley, Mont.
Newell Irrigation and Dryland Field Station.....	Newell, S. Dak.
Sheridan Substation.....	Sheridan, Wyo.

<sup>4</sup> The survey was conducted by Lyle T. Alexander, Chief, Soil Survey Laboratories, Soil Conservation Service, Beltsville, Md., who visited all the dryland stations. He was assisted by soil correlators from the Division of Soil Survey and by a representative from each of the State agricultural experiment stations. The soil correlators were: James Thorp, who assisted in Colorado, Nebraska, and Wyoming; E. H. Templin, who assisted at the Great Plains stations; W. I. Watkins, who assisted in Kansas, South Dakota, and North Dakota; B. H. Williams, who assisted in Montana; and Willis J. Leighty, who assisted in the Northwestern States.

<i>Experimental station</i>	<i>Location</i>
Archer Substation.....	Archer, Wyo.
North Platte Experiment Station.....	North Platte, Nebr.
United States Akron Field Station.....	Akron, Colo.
Colby Branch Station.....	Colby, Kans.
Fort Hays Branch Station.....	Hays, Kans.
Garden City Branch Station (main field and annex).....	Garden City, Kans.
United States Southern Great Plains Field Station.....	Woodward, Okla.
United States Lawton Field Station.....	Lawton, Okla.
United States Dalhart Field Station.....	Dalhart, Tex.
United States Big Spring Field Station.....	Big Spring, Tex.

A map showing the locations of the stations selected is presented (fig. 1). Newell, S. Dak., and North Platte, Nebr., were not included in the study of the effects of cropping on the total nitrogen and carbon content of the soil, but were included in the soluble-nitrogen studies.

The year the sod was broken at each station, the year the experimental plots were initiated, the soil series and texture, and the native vegetation of the area are presented (table 1). It will be noted that the experimental

TABLE 1.—*Identification of soils and native vegetation of 17 stations in the Great Plains. The year in which the native sod was broken and experimental plots initiated is also given for each station*

Location	Year sod broken	Year experimental plots initiated	Soil series	Soil texture	Native vegetation
Mandan, N. Dak.	1913	1914	Cheyenne.....	Fine sandy loam..	Blue grama, needlegrass, and threadgrass.
Dickinson, N. Dak.	1906	1907	Morton.....	Loam.....	Blue grama, western wheatgrass, needlegrass, and threadgrass.
Havre, Mont.....	1916	1916	Joplin.....	60 percent clay loam, 30 percent loam.	Short grasses.
Moccasin, Mont....	1907	1908	Judith.....	85 percent clay loam, 15 percent gravelly clay loam.	Blue grama, Sandberg bluegrass, needlegrass, and threadgrass.
Huntley, Mont....	1911	1912	Nunn <sup>1</sup> .....	Clay loam to silty clay.	Mostly short grasses.
Newell, S. Dak....	1907	1908	Pierre.....	Clay.....	Buffalograss, blue grama, and western wheatgrass.
Sheridan, Wyo....	1916	1917	Bridgeport.....	Loam to silt loam..	Buffalograss, blue grama, western wheatgrass, needlegrass, and threadgrass.
Archer, Wyo.....	1912	1913	Altvan.....	Loam.....	Blue grama and western wheatgrass.
North Platte, Nebr.	1896	1935	Holdrege.....	Very fine sandy loam.	Buffalograss, blue grama, and western wheatgrass.
Akron, Colo.....	1907	1908	Rago.....	Silt loam.....	Buffalograss and blue grama.
Colby, Kans.....	1905	1914	Sherman.....	Do.	Do.
Hays, Kans.....	1903	1906	Munjor <sup>1</sup> .....	Silty clay loam, silt loam.	Do.
Garden City, Kans.	1907	1907	Keith, Ulysses, Colby.	Very fine sandy loam.	Do.
Garden City, Kans., annex.	1930	1931	do.....	do.....	Do.
Woodward, Okla..	1914	1914	Pratt.....	Fine sandy loam..	Tall grasses.
Lawton, Okla....	1915	1916	Lawton.....	Silt loam.....	Do.
Dalhart, Tex.....	1907	1908	Dalhart, Otero, Mansker.	Loam to fine sandy loam.	Short grasses.
Big Spring, Tex...	1906	1915	Amarillo.....	Fine sandy loam..	Short grasses and mesquite.

<sup>1</sup> Tentative uncorrelated classification.

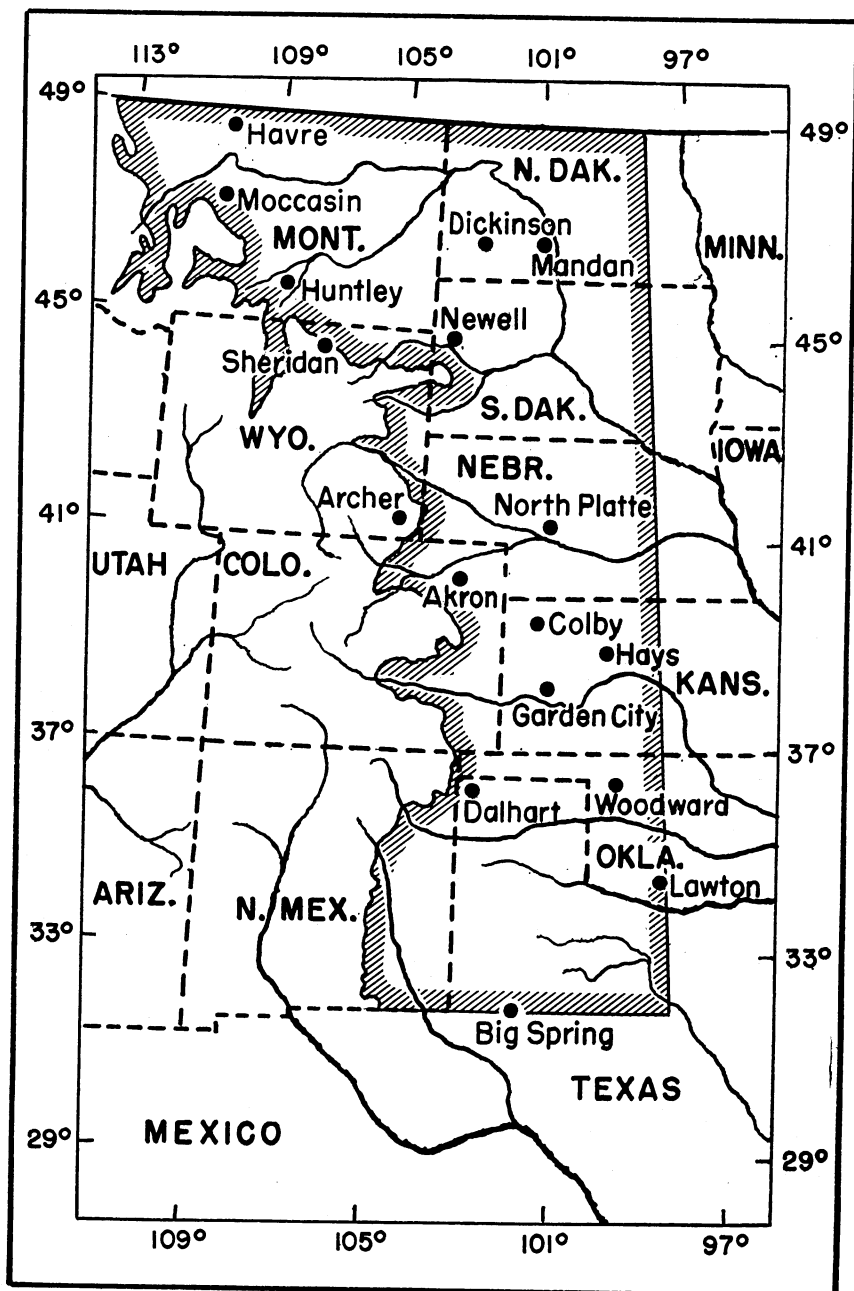


FIGURE 1.—Map of the Great Plains region, showing the location of the stations included in this study. The western boundary is indicated by the shaded line, which is also the 5,000-foot contour.

plots were initiated in the same year that the sod was broken or 1 year later at all stations except North Platte, Colby, Hays, and Big Spring. Between the time the sod was broken and the experimental plots were established at these stations, the land was uniformly cropped.

## Climate

Generally speaking, the Great Plains region is subject to wide fluctuations in precipitation, temperature, and wind velocity. Temperatures over 100° F. are not uncommon and occur even in the northern portion. Temperatures below 0° are not uncommon in the central and northern portions, and lows of more than 50° below zero have been recorded at some locations. Precipitation is generally limited, and long periods of drought may occur. The heavier rains are often of the thunderstorm type which fall rapidly and result in considerable runoff from the more sloping lands. Wind velocity is rather high at times; and this, together with high temperatures during the summer months, promotes evaporation and reduces the effectiveness of the rainfall. Prevention of soil blowing is a frequent problem in certain areas; and during prolonged periods of drought with sparse plant cover, duststorms reach destructive proportions over a wide area.

Climatic and elevation data for each location are presented (table 2). For the years covered by these data, annual precipitation ranged from 11.5 inches at Havre, Mont., to 28.7 inches at Lawton, Okla., with an average of 17.9 inches. In the areas studied, approximately three-fourths of the precipitation falls during the period April to September, inclusive.

TABLE 2.—*Climatic and elevation data for 17 stations in the Great Plains*

Location	Years of record	Precipitation		Evapora- tion <sup>1</sup>	Evapora- tion/pre- cipitation ratio <sup>2</sup>	Temper- ature	Eleva- tion
		Annual	Apr.- Sept.	Apr.- Sept.	Apr.- Sept.	Mean annual	
		<i>Inches</i>	<i>Inches</i>	<i>Inches</i>		<i>° F.</i>	<i>Feet</i>
Mandan, N. Dak.....	1915-51	15.82	10.88	32.99	3.03	41.0	1,750
Dickinson, N. Dak.....	1907-47	15.63	12.09	34.73	2.87	40.3	2,543
Havre, Mont.....	1917-50	11.50	8.86	37.33	4.21	42.0	2,505
Moccasin, Mont.....	1909-51	15.12	11.20	33.67	3.01	42.2	4,228
Huntley, Mont.....	1910-51	13.13	8.82	32.65	3.70	45.0	3,018
Newell, S. Dak.....	1908-52	15.78	12.13	35.20	2.90	45.0	2,880
Sheridan, Wyo.....	1917-51	16.17	11.26	35.31	3.14	44.3	3,790
Archer, Wyo.....	1913-51	14.78	11.65	35.30	3.03	45.0	6,012
North Platte, Nebr.....	1907-52	19.34	15.42	41.10	2.67	49.5	3,025
Akron, Colo.....	1908-51	17.40	13.81	43.19	3.13	48.8	4,650
Colby, Kans.....	1914-50	18.48	14.24	44.96	3.16	51.0	3,145
Hays, Kans.....	1907-51	23.11	17.79	47.75	2.68	53.9	2,000
Garden City, Kans.....	1908-49	18.02	13.70	54.42	3.97	53.8	2,836
Woodward, Okla.....	1915-48	23.76	16.09	51.28	3.19	58.1	1,900
Lawton, Okla.....	1916-49	28.70	18.18	45.29	2.49	61.3	1,111
Dalhart, Tex.....	1906-50	18.09	14.14	50.89	3.60	54.3	4,000
Big Spring, Tex.....	1916-50	18.87	12.79	54.37	4.25	63.0	2,396
Average (all stations).....	1911-50	17.86	13.12	41.79	3.24	49.3	3,046

<sup>1</sup> Inches of evaporation from a free-water surface, using the standard Bureau of Plant Industry type evaporation pan.

<sup>2</sup> Evaporation divided by precipitation for the period April through September.



As would be expected, there was a general increase in evaporation from north to south. These values ranged from 32.7 inches at Huntley, Mont., to 54.4 inches at Garden City, Kans., with an average for all stations of 41.8 inches.

The evaporation/precipitation ratio ranged from 2.49 at Lawton, Okla., to 4.25 at Big Spring, Tex., with an average of 3.24 for all stations. Garden City, Kans., and Havre, Mont., also had high ratios, indicating that the rainfall received at these stations may be less effective than at the stations with lower ratios.

The average annual temperatures generally increased from north to south, as expected, and ranged from 40.3° F. at Dickinson, N. Dak., to 63.0° at Big Spring, Tex. The average for all stations was 49.3°.

Elevation ranged from 1,111 feet at Lawton, Okla., to 6,012 feet at Archer, Wyo., with an average for all stations of 3,046 feet. The region as a whole slopes from west to east.

## Collection and Preparation of Samples

### Total Nitrogen and Carbon Study

Soil samples were collected at the time the rotations were established at Sheridan, Wyo.; at Woodward, Okla.; and at the Garden City (Kans.) annex. The rotation plots at Colby, Hays, and the Garden City (Kans.) main field were sampled in 1916 after being cropped for several years. These 1916 data (33) were used as the basis for determining the loss of nitrogen at the three Kansas stations.

At each of the other stations, it was necessary to locate a virgin-sod area representative of the site where the rotations were located. This was done during the survey described (p. 2). The data from these virgin areas were used to determine the loss of nitrogen or carbon that resulted from cropping.

To use these data from the virgin areas, it was necessary to assume that the nitrogen and carbon values obtained for the virgin sod in 1947 accurately represented the original condition of the rotation field; also, that the original nitrogen and carbon contents of all the plots in the field were the same. As such assumptions are subject to considerable error, only large differences between values should be regarded as significant. Greater confidence can be placed in results that are similar at a number of locations.

At Mandan, N. Dak., a high correlation was found between both the nitrogen content and the carbon content of the virgin sod and the percentage by weight of particles less than 0.005 mm. in diameter. The percentage of particles less than 0.005 mm. in diameter in the soil from the rotation plots was also determined. By substituting these values in the regression equation for virgin sod, the percentage of nitrogen or carbon that was in the soil at the time the sod was broken was calculated for each plot. A more complete description of this procedure is presented later in this bulletin (p. 8).

A grid system was used on each virgin area to determine sampling locations. Each grid was composed of 9 points—3 parallel rows of 3 points each. The points were spaced at 100- to 200-foot intervals, depending upon the size of the area. A pit was dug in each virgin area to study the characteristics of the profile. Soil samples were collected from the grids at the time the survey was made in 1947. A 1-quart sample

was taken at each of the 9 points for each of the 0- to 6-inch and 6- to 12-inch depths. The selection of the sampling sites on the general farmlands in North Dakota was made in 1950.<sup>5</sup> Only those sites were selected which were near a virgin sod area of the same soil type. All sites were located on Barnes, Morton, or Williams soils. Samples were taken from the 0- to 6-inch, 6- to 12-inch, and 12- to 18-inch depths. Each depth was a composite of several borings.

The rotation plots were sampled by or under the direction of key personnel at each station.<sup>6</sup>

Samples for the present study were collected in 1947 except those from Colby, Garden City, and Hays, Kans., which were collected in 1946 in connection with a separate study conducted by the Kansas Agricultural Experiment Station; and those from Mandan, N. Dak., which were collected in 1943.

In most instances, a 1-quart sample of soil was collected from each plot for each depth of 0 to 6 inches and 6 to 12 inches. It was sometimes necessary to alter the depth of sampling to conform to previous samplings. Each sample was a composite of several borings, usually 9 or more.

The soil samples were air-dried and shipped to the laboratory at Mandan, N. Dak., for analysis, with the exception of those from the 3 Kansas stations and those from Mandan, N. Dak.; these were analyzed at Beltsville, Md. The soil samples were crushed and passed through a 2-mm. screen; and all material that remained on the screen, such as rocks and undecomposed organic matter, was discarded.

### Soluble-Nitrogen Study

In 1949, 100 wheat plants were collected from manured and non-manured rotations at 11 of the stations, to determine the effect of barnyard manure on the uptake of nitrogen by the plants. These samples were shipped to Mandan, N. Dak., where they were oven-dried at 65° C. and ground for analysis.

In 1950, approximately 5 pounds of soil was collected from the 0- to 6-inch depth on a number of rotations at 13 of the stations. These samples were used for evaluating the effects of different levels of soil

<sup>5</sup> The selecting of the sampling sites, as well as the collecting of the samples, was done by Dr. G. A. Johnsgard, formerly professor of soils, North Dakota Agricultural College, Fargo, N. Dak.

<sup>6</sup> The authors are indebted to the personnel who collected soil and plant samples from the rotation plots and supplied information regarding the rotations. (Place names are used instead of the full designations of the respective stations; see list on p. 2.) These personnel were: Leroy Moomaw (retired), former superintendent, Dickinson, N. Dak.; V. C. Hubbard (deceased), former agronomist, M. A. Bell (deceased), former superintendent, and J. J. Sturm, superintendent, Havre, Mont.; R. M. Williams (retired), former superintendent, Moccasin, Mont.; A. E. Seamans (retired), agronomist, Huntley, Mont.; A. Osenbrug (retired), agronomist, Newell, S. Dak.; C. R. Hills, former acting superintendent, Sheridan, Wyo., and O. A. Beath, head, Department of Agricultural Research Chemistry, University of Wyoming, Laramie, Wyo.; A. L. Nelson (retired), former superintendent, Archer, Wyo., and R. D. Lewis, soil scientist, Laramie, Wyo.; L. L. Zook (retired), former superintendent, and R. E. Ramig, soil scientist, North Platte, Nebr.; J. F. Brandon, superintendent, Akron, Colo.; J. B. Kuska (retired), agronomist, Colby, Kans.; A. B. Erhart, former agronomist, and P. L. Brown, soil scientist, Hays, Kans.; H. L. Stout, former agronomist, and W. L. Rock, soil scientist, Garden City, Kans.; L. F. Locke, soil scientist, Woodward, Okla.; W. M. Osborn (retired), former superintendent, Lawton, Okla.; B. F. Barnes, former superintendent, and Grady L. Randel, former farm foreman, Dalhart, Tex.; and F. E. Keating, superintendent, Big Spring, Tex.

nitrogen on the ability of the soils to produce nitrates, as determined by incubation in a room at constant temperature. These soils were air-dried immediately and shipped to Mandan, N. Dak., for incubation and analysis. They were passed through a 2-mm. screen, and all material that remained on the screen, such as rocks and undecomposed organic matter, was discarded.

### Analytical Procedures

The total nitrogen content of the soil was determined by the Gunning method (3) with a few modifications. The catalyst used in digestion was 10 parts  $K_2SO_4$ , 1 part  $FeSO_4$  and 0.5 parts  $CuSO_4$ . The  $NH_3$  was distilled into a 4-percent solution of boric acid, and titrated with N/7  $H_2SO_4$  or N/10  $HCl$ . A mixture of bromcresol green and methyl red was used as the indicator.

At first, carbon determinations were made by the dry-combustion method, which included both the inorganic and organic carbon. It was then necessary to determine the inorganic carbon and deduct this from the total carbon value, to obtain the organic-carbon content. Later, the wet-combustion procedure (35), which was more rapid, was used to estimate the organic-carbon content.

The incubation procedure for determining the quantity of nitrate-nitrogen produced by the soil for a given period of time was essentially the same as that used by Allison and Sterling (2) with a few modifications. The procedure used was as follows:

A quantity of soil, equivalent to 50 gm. oven-dried, was placed in 8-ounce jars. This included 1 gm. of garden soil to assure the presence of nitrifying organisms. To this was added 12.0 mg. of dipotassiumphosphate and 0.5 gm. of  $CaCO_3$ . The samples were kept in a room held at a constant temperature of  $28^\circ C$ . and moisture was maintained in the soil at the moisture equivalent by weekly additions of water. The soil was shaken or stirred once a week to promote aeration. All the soils were incubated for a 6-week period and a few for 12-, 18-, and 24-week periods. The nitrate-nitrogen was determined by the usual phenol-disulfonic acid procedure at the beginning and again at the end of each period. The quantity of nitrate in the soil at 0 weeks, as well as the quantity produced by 1 gm. of garden soil, was deducted from the total quantity produced at the end of each period to obtain the quantity of nitrates produced during each period.

The nitrogen content of the plant material was determined by a modification of the procedure used for soil so as to include nitrate-nitrogen (3). Phosphorus content of the wheat plants was determined by the vanadomolybdate method.

The standard pipette procedure was used for mechanical analysis.

### Relationship Between Soil Nitrogen and Particle Size

As mentioned previously (p. 6), a high correlation was obtained at Mandan, N. Dak., between the nitrogen or carbon content of the virgin sod and the percentage of particles less than 0.005 mm. in diameter. The relationship for nitrogen is shown (fig. 2). The percentage of particles less than 0.005 mm. in diameter was then determined on each of the rotation plots studied. By substituting these values in the regression equation obtained from the virgin sod, an estimate of the nitrogen content prior to the time the sod was broken could be obtained for each plot. It was assumed that the nitrogen content of the virgin sod did not change appreciably during the 30-year period of study, and that the quantity of less than 0.005-mm. material in the plots had not changed during the period of cultivation.

It was hoped that such a procedure could be used at the other stations where original soil samples were not collected. However, poor correlations were obtained at many of the other stations, and the procedure was used only at Mandan. Perhaps if more samples had been collected from the virgin sod, the correlations would have become significant.

To obtain an overall estimate of the relationship between soil nitrogen and particle size, the data from the virgin-sod areas at all of the stations were grouped together. A total of 118 samples were available. The data are plotted (fig. 3), together with the regression line. The data

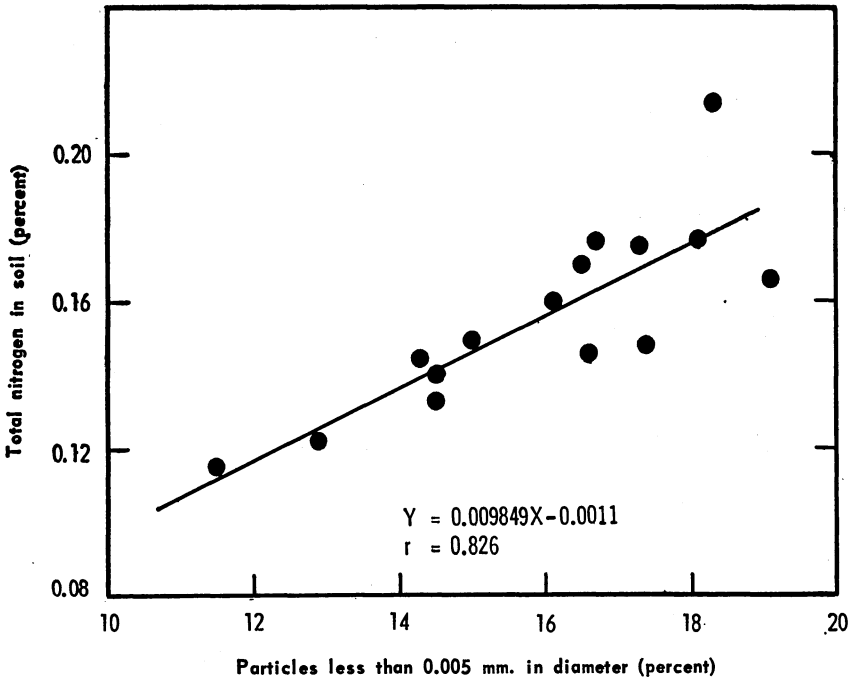


FIGURE 2.—Relationship of percentage of total nitrogen in virgin soil to the percentage of particles less than 0.005 mm. in diameter at Mandan, N. Dak.

from the individual stations are identified by different symbols, and the poor relationship between the 2 variables at some stations can be noted. For example, at Dickinson and Hays, the points are widely scattered, while at Moccasin, the correlation is negative. Although the data from Sheridan are arranged in a linear group, the regression line for these data would be nearly horizontal and the correlation coefficient nonsignificant.

The correlation coefficient for all samples was 0.617 which was much higher than required to be significant at the 1-percent level. Although the coefficient was highly significant, only 36 percent of the variation in nitrogen content could be accounted for by differences in the content of particles less than 0.005 mm. in diameter. It will be noted that in general the relationship was much closer for coarser textured soils that contained less than 30 percent of particles under 0.005 mm. in size.

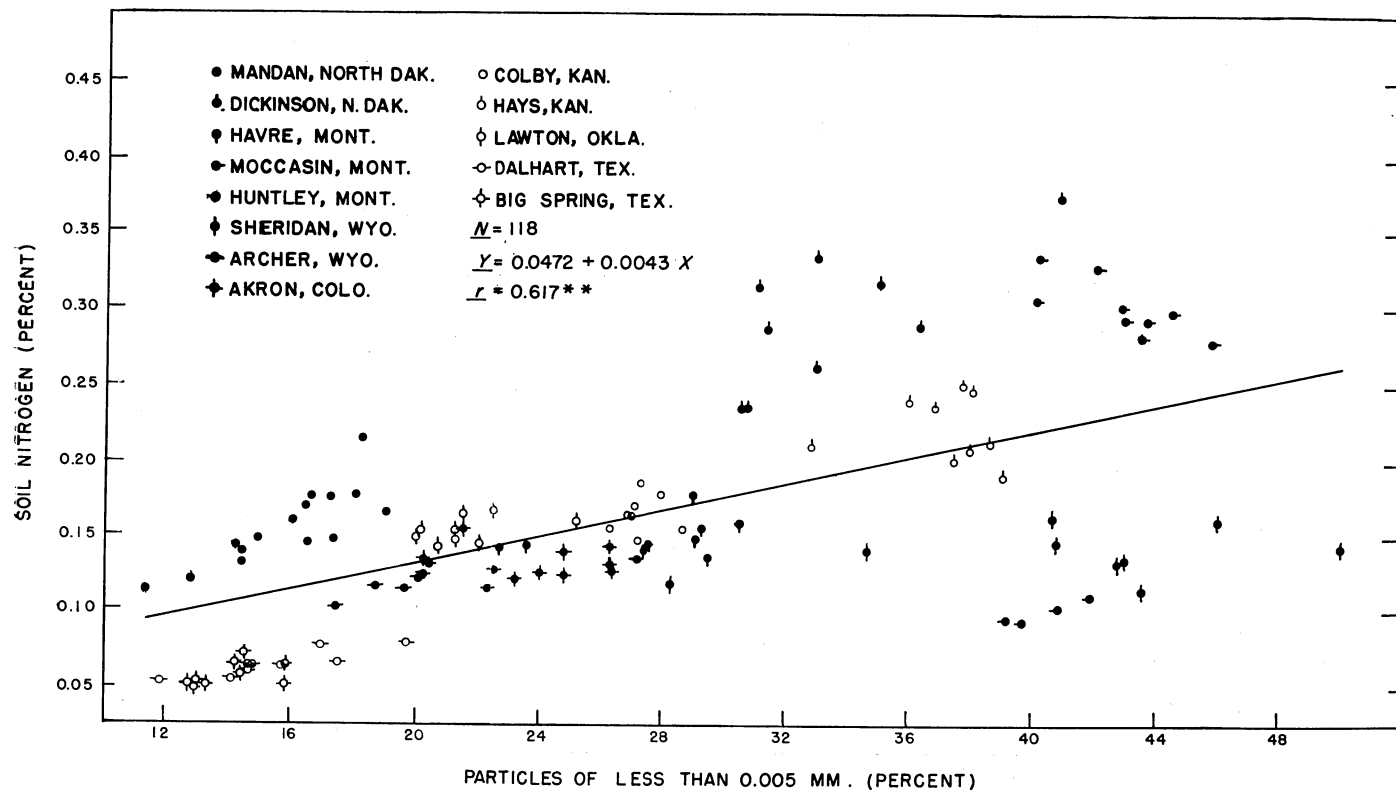


FIGURE 3.—Relationship of percentage of nitrogen to percentage of particles less than 0.005 mm. in diameter in the surface soil of virgin sod at 13 locations in the Great Plains. (The 2 asterisks (\*\*) indicate significant at 1-percent level.)

This method of determining what the nitrogen content of cultivated soils was prior to the time the sod was broken may have merit on certain soils, but if it is used, a rather large number of samples should be collected.

## Comparison of Nitrogen and Carbon Content of Virgin and Cropped Soils

A comparison of the total nitrogen content of unmanured cropped and virgin surface soils at 14 locations in the Great Plains is shown (table 3). The average loss of total nitrogen in surface soils at the 14 locations over a 36-year cropping period was 39 percent. This represents a 1.07-percent loss of soil nitrogen for each year of crop production.

TABLE 3.—Total nitrogen changes in surface soils (0- to 6-inch depth, except as indicated) at 14 locations in the Great Plains, as affected by 36 years of cropping

Location	Cropping period	Years of cropping	Total nitrogen content			
			Virgin soils <sup>1</sup>	Cropped soils <sup>2</sup>	Change with cropping	Change per year of cropping
		Number	Percent	Percent	Percent	Percent
Mandan, N. Dak.....	1913-43	30	0.160	0.116	-23	-0.93
Dickinson, N. Dak.....	1907-47	40	.293	.149	-49	-1.23
Hayre, Mont.....	1916-47	31	.151	.090	-40	-1.29
Moccasin, Mont.....	1908-47	39	.300	.205	-32	-.82
Sheridan, Wyo.....	1917-47	30	.159	.121	-24	-.80
Archer, Wyo.....	1913-47	34	.122	.082	-33	-.97
Akron, Colo.....	1908-47	39	.134	.086	-36	-.92
Colby, Kans.....	1905-46	41	.165	.105	-36	-.88
Hays, Kans.....	1903-46	43	.220	.122	-45	-1.05
Garden City, Kans.....	1907-46	39	.120	.077	-36	-.92
Woodward, Okla.....	1914-47	33	.080	.032	-60	-1.82
Lawton, Okla.....	1916-47	31	.154	.074	-52	-1.68
Dalhart, Tex.....	1908-47	39	.067	.042	-37	-.95
Big Spring, Tex.....	1906-47	41	.060	.041	-32	-.78
Average.....		36	.156	.096	-39	-1.07

<sup>1</sup> Except at Mandan, Sheridan, and Woodward, virgin areas closely comparable in soil characteristics to each of the cropped-soil areas were sampled in 1947. At Mandan, the sampling date was 1943. At Sheridan and Woodward, virgin- and cropped-soil samples were taken from the same field; the virgin samples were collected when the sod was originally broken in 1917 and 1914, respectively.

<sup>2</sup> Cropped soils sampled at the end of the cropping period. Values reported for cropped soils are averages of all cropping treatments except those receiving manure.

<sup>3</sup> Values are for 0- to 12-inch depth.

Soil nitrogen losses due to cropping have varied among locations, ranging from 60 percent at Woodward, Okla., to only 24 percent at Sheridan, Wyo. These percentage loss values, however, are relatively constant when compared with the wide range in nitrogen contents of virgin and cropped soils under investigation. For example, virgin soils varied in total nitrogen content between 0.300 percent at Moccasin, Mont., and 0.060 percent at Big Spring, Tex.; cropped soils varied between 0.205 percent at Moccasin, Mont., and 0.032 percent at Woodward, Okla. Even though the total nitrogen content of virgin soils showed a five-fold variation among locations, cropping and cultivating have caused a relatively constant percentage reduction in nitrogen level.

Variations among locations in the nitrogen content of virgin soils, as well as the degrees of change of this soil constituent because of cropping, may be somewhat related to climate, soil, and other environmental factors.

In general, the nitrogen content of the coarse-textured soils was lower than that of the silt loam, loam, and clay loam soils. Soils from the more southerly locations were generally lower in total nitrogen in their virgin state than from those locations in the north. These results were in agreement with those of Jenny (24). While there were many notable exceptions, the decline in soil nitrogen with cropping was most striking at locations having the highest annual precipitation. The high rates of loss at Havre, Mont., and Dickinson, N. Dak., however, were not explainable on this basis.

At 11 locations where the organic carbon contents of unmanured cultivated and virgin soils were investigated (table 4), the average loss per year over a 37-year cropping period was 1.15 percent. Results obtained by Smith and coworkers (42) from the Texas Blacklands showed an average annual decline in organic matter of 1.50 percent in the plow layer. At all locations, cropping caused a greater percentage reduction in organic carbon than in nitrogen content. As an average of the 11 soils, 42 percent of the organic carbon in virgin soils was lost in 37 years of cropping. For this same period and group of soils, 36 percent of the nitrogen was lost.

The relationship between the carbon and nitrogen contents of the cultivated and virgin soils and the changes in these relationships with cropping are shown by the carbon/nitrogen (C/N) ratios (table 5). The average C/N ratio of 7 virgin soils was 11.1; that of comparable cultivated soils was 10.1. Thus, the reduction in the C/N ratio of these soils after 37 years of cropping has averaged 1.0; this is approximately a 9-percent reduction based on the average C/N ratio of the virgin soils. While the magnitude of the change in the C/N ratio is not great, it would appear to be a significant one in view of the similarity in trend for all of the 11 soils under investigation.

TABLE 4.—Organic carbon changes in surface soils (0- to 6-inch depth) at 11 locations in the Great Plains, as affected by 37 years of cropping

Location	Cropping period	Years of cropping	Organic-carbon content			
			Virgin	Cropped	Change with cropping	Change per year of cropping
		<i>Number</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Mandan, N. Dak. ....	1913-43	30	2.11	1.45	-31	-1.03
Dickinson, N. Dak. ....	1907-47	40	3.64	1.51	-59	-1.48
Havre, Mont. ....	1916-47	31	1.75	.83	-53	-1.71
Moccasin, Mont. ....	1908-47	39	3.24	2.19	-32	-.85
Sheridan, Wyo. ....	1917-47	30	1.66	1.19	-28	-.93
Archer, Wyo. ....	1913-47	34	1.33	.78	-41	-1.21
Akron, Colo. ....	1908-47	39	1.42	.77	-46	-1.18
Colby, Kans. ....	1905-46	41	1.83	1.01	-45	-1.10
Hays, Kans. ....	1903-46	43	2.47	1.21	-51	-1.19
Garden City, Kans. ....	1907-46	39	1.13	.69	-39	-1.00
Dalhart, Tex. ....	1908-47	39	.72	.44	-39	-1.00
Average .....		37	1.04	1.10	-42	-1.15

Cropping has also been associated with decline in carbon and nitrogen fractions of subsurface layers of soil (table 6). The average annual loss at 7 stations was 0.40 percent of nitrogen and 0.53 percent of organic carbon. The average period of years of cropping at these 7 sta-

tions was 35. During this period an average of 15 percent of the nitrogen was lost as well as 20 percent of the organic carbon. Here again, the greater loss of carbon than nitrogen is evident even in the subsurface soils.

TABLE 5.—Carbon/nitrogen ratio of cropped and virgin surface soils (0- to 6-inch depth) at 11 locations in the Great Plains

Location	Years of cropping	Carbon/nitrogen ratio		
		Virgin soils	Cropped soils	Change with cropping
	<i>Number</i>			
Mandan, N. Dak.....	30	13.2	12.5	-0.7
Dickinson, N. Dak.....	40	12.4	10.9	-1.5
Havre, Mont.....	31	11.6	9.2	-2.4
Moccasin, Mont.....	39	10.8	10.7	-.1
Sheridan, Wyo.....	30	10.4	9.8	-.6
Archer, Wyo.....	34	10.9	9.5	-1.4
Akron, Colo.....	39	10.5	9.9	-.6
Colby, Kans.....	41	11.1	9.6	-1.5
Hays, Kans.....	43	11.2	9.9	-1.3
Garden City, Kans.....	39	9.4	9.0	-.4
Dalhart, Tex.....	39	10.7	10.5	-.2
Average.....	37	11.1	10.1	-1.0

TABLE 6.—Total nitrogen and organic-carbon changes in subsurface layers of soil at 7 locations in the Great Plains, as affected by 35 years of cropping

#### TOTAL NITROGEN CONTENT

Station	Years of cropping	Soil depth	Virgin soils	Cropped soils	Change with cropping	Change per year of cropping
	<i>Number</i>	<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Mandan, N. Dak.....	30	6-12	0.119	0.109	-8	-0.27
		12-24	.084	.080	-5	-.17
Dickinson, N. Dak.....	40	6-12	.163	.107	-34	-.85
Havre, Mont.....	31	6-12	.108	.090	-17	-.55
Sheridan, Wyo.....	30	7-20	.117	.105	-10	-.33
Archer, Wyo.....	34	6-12	.089	.084	-6	-.18
Akron, Colo.....	39	6-12	.087	.081	-7	-.18
Dalhart, Tex.....	39	6-12	.059	.050	-15	-.38
Average.....	35	6-12	.104	.087	-15	-.40

#### ORGANIC-CARBON CONTENT

Mandan, N. Dak.....	30	6-12	1.49	1.36	-6	-0.20
		12-24	1.01	.95	-6	-.20
Dickinson, N. Dak.....	40	6-12	1.87	.98	-48	-1.20
Havre, Mont.....	31	6-12	.99	.82	-17	-.55
Sheridan, Wyo.....	30	7-20	1.21	1.07	-12	-.40
Archer, Wyo.....	34	6-12	.83	.76	-8	-.24
Akron, Colo.....	39	6-12	.79	.65	-18	-.46
Dalhart, Tex.....	39	6-12	.60	.48	-20	-.51
Average.....	35	6-12	1.10	.84	-20	-.53

To compare the results obtained from experimental stations with those obtained under general farm conditions, virgin and cropped soils from farms in North Dakota were analyzed for nitrogen and carbon. These farms were located on Barnes, Morton, and Williams soils. A summary of the results is presented (table 7).



TABLE 7.—Summary of average percentage of nitrogen and carbon and the carbon/nitrogen ratio for 3 soil series under virgin sod and cropped land in North Dakota

Soil Series	Fields		Years cropped	Depth	Nitrogen			Carbon			Carbon/nitrogen ratio		
	Virgin land	Cropped land			Virgin land	Cropped land	Change	Virgin land	Cropped land	Change	Virgin land	Cropped land	Change
	Number	Number	Number	Inches	Percent	Percent	Percent	Percent	Percent	Percent			
Barnes.....	8	7	57	{ 0-6	0.415	0.254	-39	4.97	2.77	-44	12.0	10.9	-1.1
				{ 6-12	.210	.130	-38	2.22	1.12	-50	10.6	8.6	-2.0
				{ 12-18	.120	.088	-27	1.12	.72	-36	9.3	8.2	-1.1
Morton.....	6	7	40	{ 0-6	.242	.186	-23	2.88	2.02	-30	11.9	10.9	-1.0
				{ 6-12	.147	.134	-9	1.54	1.39	-10	10.5	10.4	-.1
				{ 12-18	.114	.102	-11	1.17	.99	-15	10.3	9.7	-.6
Williams.....	6	7	33	{ 0-6	.285	.193	-32	3.35	1.99	-41	11.8	10.3	-1.5
				{ 6-12	.146	.115	-21	1.42	1.00	-30	9.7	8.7	-1.0
				{ 12-18	.110	.091	-17	1.02	.78	-24	9.3	8.6	-.7
Average, all soils.....	20	21	43	{ 0-6	.324	.211	-35	3.86	2.26	-41	11.9	10.7	-1.2
				{ 6-12	.172	.126	-27	1.77	1.17	-34	10.3	9.3	-1.0
				{ 12-18	.115	.094	-18	1.11	.83	-25	9.7	8.8	-.9

It will be noted that these results are somewhat in line with those obtained from the experimental stations. The average nitrogen loss for all surface soils was 35 percent, and the average carbon loss 41 percent. The carbon/nitrogen ratio for all surface soils was reduced 1.2 by cropping. The higher nitrogen Barnes soils have been cropped for a longer period, which would no doubt increase nitrogen losses; but there is evidence that the soils with greater nitrogen content lost a higher percentage of their nitrogen. Thus, cropping tends to decrease the variability in nitrogen between soils. It is also apparent that comparatively high losses have occurred in the subsurface soils.

These results, together with those from the experimental stations, emphasize the fact that sizable losses of nitrogen and carbon occurred in the Great Plains soils after they were placed under cultivation. This verifies the findings mentioned in the literature (5, 9, 18, 21, 25, 31, 33, 34, 37, 47).

### Rate of Decline in Soil Nitrogen with Years of Cropping

Earlier work by Gainey and coworkers (18), Sewell and Gainey (40), and Myers and coworkers (33) at 3 Kansas stations, as well as periodic sampling and analyses by Prof. O. A. Beath on the rotation plots at Sheridan, Wyo., made it possible to show graphically the trend in the nitrogen content of the soil over a period of years at these 4 locations. The decline in nitrogen content of the soil with years of cropping at Hays, Colby, and Garden City, Kans., and at Sheridan, Wyo., is presented (fig. 4). At Garden City, 2 experimental fields were available.

The soil was not analyzed for nitrogen at the time the sod was broken at Hays and Colby, Kans., and at the Garden City, Kans., main field; therefore the nitrogen content of virgin-sod areas sampled in 1946 was used for the beginning of the period. It was therefore assumed that the nitrogen content of the sod had not changed from the time the sod was broken until 1946, and that the virgin-sod area at each station was representative of the experimental plots.

Samples were collected from the Garden City annex and from the plots at Sheridan at the time the sod was broken; the data at these 2 locations were therefore complete. Each curve (fig. 4) represents an average of a number of rotations at each station. Rotations to which barnyard manure had been applied were excluded.

It is evident from the graph that at the 3 Kansas stations, the nitrogen content declined sharply during the first 10 to 20 years. After that, the rate of decline decreased. This was particularly true of the 2 locations at Garden City. At Sheridan, the decline was almost a straight line with no tendency to level off.

It will also be noted that, with increasing years of cropping at the 3 Kansas stations, the differences in nitrogen content of the soil between locations become narrower. Near the end of the period, however, the curves are nearly parallel.

The period covered by these curves is too short to provide any indication of future trends. The higher nitrogen soil could continue to lose nitrogen at a greater rate than the lower-nitrogen soil, so that at some time in the distant future the soils at these 3 Kansas locations would be similar in nitrogen content. Or it is possible that the soils would reach equilibrium levels with different nitrogen contents.

Jenny (24) has discussed trends of soil nitrogen, and Woodruff (50) has presented a formula for calculating the equilibrium level of a soil under a given cropping treatment. In discussing the equilibrium concept, Jenny states (*p.* 255) that "nitrogen may reach a definite level or stationary state that depends on the productivity variables, climate, plant, soil, and

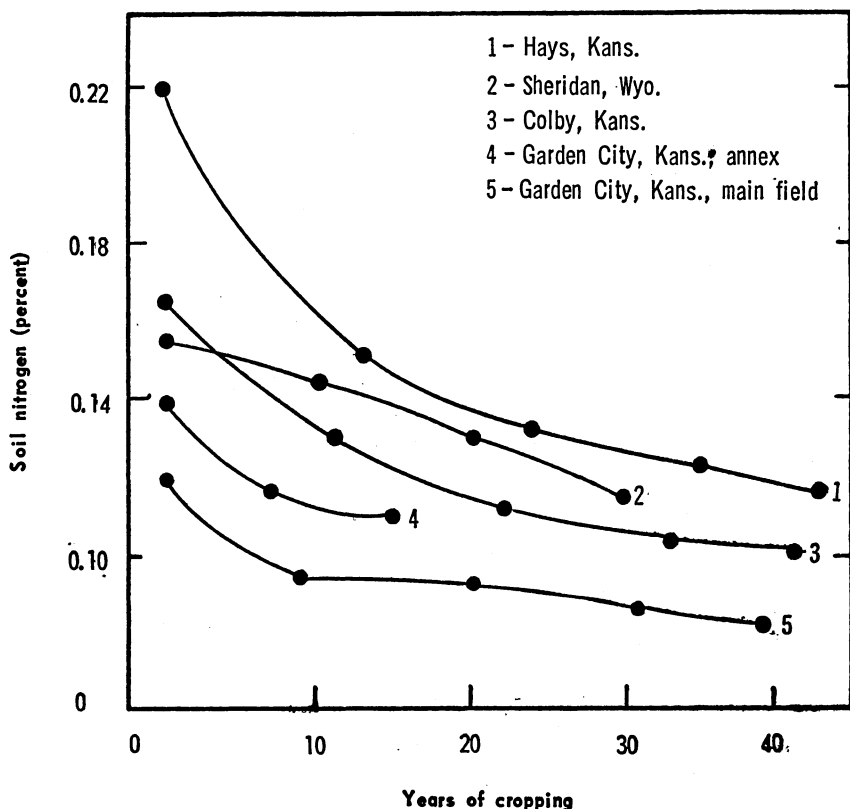


FIGURE 4.—Decline in nitrogen percentage of the soil at Hays, Colby, and Garden City, Kans., and Sheridan, Wyo., with years of cropping.

management." Thus, according to this statement, each of these soils would eventually reach different equilibrium levels of nitrogen if the same cropping systems were continued that had been used in the past.

### Influence of Specific Cropping Practices on the Total Nitrogen and Carbon Content and the Carbon/Nitrogen Ratio of the Soil

Detailed data from each location are presented in appendix tables 29 to 44, inclusive. Several comparisons were made of the effects of different crops or cropping practices on the nitrogen and carbon contents of the soil; these are discussed separately in the following sections.

## Effects of Small Grains

At a number of locations, several types of small grains were grown both continuously and alternating with fallow. To determine whether there was any difference in the loss of soil nitrogen and carbon under various small grains, the percentage change in nitrogen and carbon was determined for each small grain. The average values of 2 continuously cropped and 2 alternately cropped and fallowed plots were used for each type of small grain. The nitrogen and carbon results are presented (tables 8 and 9, respectively).

TABLE 8.—*Effects of various types of small grains on percentage loss of nitrogen in surface and subsurface soils under continuous and alternate cropping and fallow, compared with virgin sod<sup>1</sup> at 9 locations in the Great Plains*

SURFACE SOILS<sup>2</sup>

Location	Years of cropping	Continuous cropping					Alternate fallow				
		Winter wheat	Spring wheat	Oats	Barley	Spring rye	Winter wheat	Spring wheat	Oats	Barley	Spring rye
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Mandan, N. Dak.....	30	-----	-20	-20	-16	-----	-----	-26	-28	-28	-----
Dickinson, N. Dak.....	40	-----	-45	-47	-41	-----	-----	-49	-53	-48	-----
Havre, Mont.....	31	-27	-42	-32	-----	-39	-35	-42	-39	-----	-42
Moccasin, Mont.....	39	-33	-29	-26	-24	-23	-31	-35	-37	-36	-37
Sheridan, Wyo.....	30	-27	-21	-20	-22	-----	-15	-27	-25	-28	-----
Archer, Wyo.....	34	-28	-30	-23	-30	-----	-33	-33	-33	-35	-----
Akron, Colo.....	39	-----	-31	-26	-25	-----	-41	-40	-33	-30	-----
Colby, Kans.....	30	-25	-9	-2	-14	-----	-26	-15	-14	-15	-----
Hays, Kans.....	30	-14	-----	-10	-7	-----	-3	-----	-8	-8	-----
Average of 4 locations.....	33	-28	-22	-18	-23	-----	-26	-28	-27	-29	-----
Average of 7 locations.....	35	-----	-26	-23	-25	-----	-----	-32	-32	-31	-----

SUBSURFACE SOILS<sup>2</sup>

Mandan, N. Dak.....	30	-----	+4	0	+3	-----	-----	-5	-10	-9	-----
Dickinson, N. Dak.....	40	-----	-28	-30	-19	-----	-----	-37	-41	-38	-----
Havre, Mont.....	31	0	-19	-11	-----	-19	-4	-12	-17	-----	-31
Sheridan, Wyo.....	30	-9	-1	+4	+3	-----	-4	-9	-14	-16	-----
Archer, Wyo.....	34	-11	+3	+6	-1	-----	-1	-9	-2	-9	-----
Akron, Colo.....	39	-----	-2	+1	+3	-----	-----	-13	-13	-8	-----
Average of 2 locations.....	32	-10	+1	+5	+1	-----	-2	-9	-8	-12	-----
Average of 5 locations.....	35	-----	-5	-4	-2	-----	-----	-15	-16	-16	-----

<sup>1</sup> The plots at Colby and Hays were sampled in 1916, and these values were used for determining percentage of change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches, and the subsurface samples from 6 or 7 to 12 inches. At Sheridan, the subsurface samples were taken from a depth of 6½ to 20 inches.

The results show that the losses of nitrogen or carbon were not consistently greater for any one type of small grain at all locations. The extent of loss was influenced to a certain extent by the adaptability and production of each small grain at a given location. No doubt soil variability also affected the results at some of the stations. It is difficult to determine from these results whether any one type of small grain influenced nitrogen and carbon losses more than any other type for the region as a whole.

TABLE 9.—*Effects of various types of small grains on percentage loss of carbon in surface and subsurface soils under continuous and alternate cropping and fallow, compared with virgin sod,<sup>1</sup> at 6 locations in the Great Plains*SURFACE SOILS<sup>2</sup>

Location	Years of cropping	Continuous cropping					Alternate fallow				
		Winter wheat	Spring wheat	Oats	Barley	Spring rye	Winter wheat	Spring wheat	Oats	Barley	Spring rye
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Mandan, N. Dak.-----	30	-----	-22	-24	-18	-----	-----	-28	-32	-30	-----
Havre, Mont.-----	31	-40	-50	-46	-----	-49	-50	-53	-53	-----	-55
Sheridan, Wyo.-----	30	-29	-27	-25	-33	-----	-28	-36	-34	-37	-----
Archer, Wyo.-----	34	-37	-32	-35	-37	-----	-40	-41	-43	-46	-----
Colby, Kans.-----	30	-38	-13	-3	-20	-----	-40	-23	-14	-12	-----
Hays, Kans.-----	30	-19	-----	-25	-33	-----	-17	-----	-18	-27	-----
Average of 3 locations.---	31	-35	-24	-21	-30	-----	-36	-33	-30	-32	-----
Average of 4 locations.---	31	-----	-24	-22	-27	-----	-----	-32	-31	-----	-----

SUBSURFACE SOILS<sup>2</sup>

Mandan, N. Dak.-----	30	-----	+2	-2	+4	-----	-----	-6	-11	-8	-----
Havre, Mont.-----	31	0	-15	-9	-----	-16	-5	-9	-20	-----	-31
Archer, Wyo.-----	34	-13	+5	+1	-1	-----	-11	-12	-11	-11	-----
Average of 2 locations.---	32	-6	-5	-4	-----	-----	-8	-10	-16	-----	-----

<sup>1</sup> The plots at Colby and Hays were sampled in 1916, and the values obtained were used for determining percentage of change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches, and the subsurface samples from 6 or 7 to 12 inches. At Sheridan, the subsurface samples were taken from a depth of 6½ to 20 inches.

At several of the locations, the differences are probably within the experimental error, while at others there may be a real difference. Myers and coworkers (33), reporting on the results from Hays and Colby, Kans., for a shorter period of time, stated that the several small grains had essentially the same effect on the soil nitrogen. Their conclusions were based on adjusted nitrogen values to compensate for soil variation.

### Continuous Cropping Versus Fallow for Small Grains and Row Crops

A comparison of the effects of small grains and row crops, grown continuously or alternating with fallow, on the nitrogen content of the soil is shown (table 10). Loss of nitrogen from surface soils under small grains was considerably less than under row crops. The same was true for the subsurface soils at most of the locations. Loss of nitrogen from the subsurface soils was considerably less than from the surface soils at nearly all locations, as would be expected.

It will also be noted that the loss of nitrogen under small grains was greater for the alternate-cropping and fallow treatment than for continuous cropping at all stations except Big Spring. Moisture-equivalent data from Big Spring indicate that soil from both the continuous and alternate wheat and fallow plots was of finer texture than that from virgin sod, and that soil from alternate fallow plots was of finer texture than that from the continuous plots. It is possible that the original nitrogen content of the wheat plots was higher than that of the virgin sod,

which would account in part for the small loss presented (table 10). It is also possible that the original nitrogen content of the alternate fallow plots was higher than that of the continuous plots; this would explain the greater loss shown for continuous cropping than for alternate fallow.

TABLE 10.—Percentage change in nitrogen of surface and subsurface soils compared with virgin sod,<sup>1</sup> under continuous and alternate cropping and fallow for small grains and row crops at 14 locations in the Great Plains

Location	Years of cropping	Surface soils <sup>2</sup>				Subsurface soils <sup>2</sup>			
		Small grains		Row crops		Small grains		Row crops	
		Continuous cropping	Alternate fallow	Continuous cropping	Alternate fallow	Continuous cropping	Alternate fallow	Continuous cropping	Alternate fallow
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Mandan, N. Dak.....	30	-18	-27	-36	-40	+2	-8	-14	-18
Dickinson, N. Dak.....	40	-44	-50	-59	-60	-25	-39	-49	-44
Havre, Mont.....	31	-35	-40	-50	-53	-12	-16	-24	-32
Moccasin, Mont.....	39	-27	-35						
Sheridan, Wyo.....	30	-22	-33	-35	-35	-4	-16	-10	-13
Archer, Wyo.....	34	-26	-34	-41	-41	0	-6	-12	-11
Akron, Colo.....	39	-28	-34	-48	-56	+1	-11	-16	-20
Colby, Kans.....	30	-9	-25	-30	-35				
Hays, Kans.....	30	-10	-15	-33	-38				
Garden City, Kans.....	30	-11	-13	-28	-27				
Woodward, Okla.....	33			-55	-64				
Lawton, Okla.....	31	-47	-49	-62	-60	-17	-24	-23	-21
Dalhart, Tex.....	39			-36	-40			-14	-17
Big Spring, Tex.....	41	-15	0	-47	-43	0	+8	-10	-6
Average of 11 locations.....	33	-24	-29	-43	-43				
Average of 8 locations.....	34	-29	-33	-47	-48	-7	-14	-20	-21

<sup>1</sup> The plots at Colby, Hays, and Garden City were sampled in 1916, and these values were used for determining percentage of change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The values for Woodward are for the 0- to 12-inch depth. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6½ to 20 inches.

The loss of nitrogen was greater under alternate row crop and fallow than under continuous row crops at only 7 out of 13 stations. The average loss of nitrogen from the surface soil for those locations where data were available for all treatments in both depths was 29 percent for continuous small grains, 33 percent for alternate small grains and fallow, 47 percent for continuous row crops, and 48 percent for alternate row crops and fallow. For the subsurface soil, the losses were 7, 14, 20, and 21 percent, respectively.

The fact that small grains, especially those grown continuously, have been much less destructive to soil nitrogen than row crops, verifies the findings of previous investigators (18, 24, 33, and 39). The wheat at most of the locations was generally harvested with a binder, and the straw removed for the major portion of the period was reported.

A few of the stations began using combines in the early 1930's, about midway in the period. If combines had been used during the entire period, perhaps the loss of nitrogen would have been even less under wheat. Most of the row crops were harvested with a binder and the entire crops removed, leaving little crop residue on the land.

The greater loss of nitrogen from row-crop land than from small-grain land was due to several factors. The amount of nitrogen removed by row crops may have been greater than that removed by small grains, which would account for part of the difference in loss. If cultivation promotes loss of nitrogen by volatilization, a greater loss could be expected under intertilled crops than under small grains. Leaching of the nitrogen below the depth of sampling may have been greater under row crops, and wind and water erosion may also have been more severe under these crops at some locations.

The fact that alternate small grains and fallow may show a greater loss of nitrogen than continuous small grains has been known for some time. Thatcher (45) reported in 1912 that workers in Minnesota, North Dakota, and Nebraska found a greater loss of nitrogen under fallow. He stated that this was probably caused almost entirely by volatilization, inasmuch as leaching would not account for the loss under dryland conditions.

Smith and Vandecaveye (41) reported on data obtained in Washington, and Newton and coworkers (34) referred to results obtained in Canada, which showed higher losses under alternate small grains and fallow than under continuous small grains.

Lyon (28), reporting on an investigation conducted at Cornell in lysimeters, showed that soil which was kept bare for 10 years and cropped for 5 years had an average annual loss of 25 pounds of nitrogen per acre; this could not be accounted for by removal of crops and drainage water. When the soil was cropped throughout the period, there was no loss that could not be accounted for by removal in crops and drainage water. He stated that the lack of vegetation is evidently a factor in increasing the loss of nitrogen in gaseous form. He also stated that other factors may contribute to the loss of nitrogen in gaseous form—tilling or stirring the soil, high nitrogen content of the soil, application of large quantities of nitrogenous manures, and possibly the application of lime to some soils.

Broadbent (7), working with certain soils in California, concluded that part of the large losses of nitrogen from those soils is probably the result of aerobic denitrification.

At Sheridan, Wyo., 1 plot had been continuously fallowed for 30 years; that is, no crop had been grown, and the plot was cultivated to control weeds. This plot had lost 43 percent of its nitrogen from the surface 7 inches of the soil during that period; this was a greater loss than had occurred on any of the other cropping treatments. This plot, however, was subject to considerable wind and water erosion, which would account in part for the high loss of nitrogen.

Naturally, the less cover there is on a soil, the more subject that soil is to wind and water erosion. Numerous investigators have reported on such losses (12, 13, 14, 23, 27, 32, 36, 38, 49). Although no actual measurements were made, it is believed that in most instances the loss of soil by wind or water erosion from the plots reported on in this study was slight and certainly would not be as great as from large fields. Volatilization may account for a portion of the greater loss of nitrogen from fallowland, and it is possible that leaching of nitrogen to depths below those which were sampled may also have been a factor. This nitrogen

would probably still be available to the plants in most years under dryland conditions, but it could not be accounted for in the depths sampled in this study.

The loss of nitrogen under alternate small grains and fallow may appear to be only slightly greater than under continuous cropping; but considering the fact that at most locations less crop is removed from the land under a fallow system, the differences in nitrogen loss become more significant. These differences emphasize the importance of factors other than crop removal. The average amount of wheat removed per plot at 8 locations under the alternate crop and fallow system was approximately 86 percent of that under continuous cropping. Where corn was used, the amount of grain removed was approximately 62 percent.

A comparison of the effect of small grains and row crops, grown continuously or alternating with fallow, on the organic-carbon content of the soil is presented (table 11). The situation for organic carbon was much the same as for nitrogen, although the percentage loss of carbon was greater than for nitrogen with a few exceptions in the subsurface soil.

TABLE 11.—*Percentage change in organic carbon of surface and subsurface soils compared with virgin sod,<sup>1</sup> under continuous and alternate cropping and fallow for small grains and row crops at 7 locations in the Great Plains*

Location	Years of cropping	Surface soils <sup>2</sup>				Subsurface soils <sup>2</sup>			
		Small grains		Row crops		Small grains		Row crops	
		Contin- uous crop- ping	Alter- nate fallow	Contin- uous crop- ping	Alter- nate fallow	Contin- uous crop- ping	Alter- nate fallow	Contin- uous crop- ping	Alter- nate fallow
	Num- ber	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent
Mandan, N. Dak.....	30	-22	-28	-38	-44	+2	-6	-18	-19
Havre, Mont.....	31	-46	-53	-62	-65	-10	-17	-27	-34
Sheridan, Wyo.....	30	-28	-34	-41	-44				
Archer, Wyo.....	34	-35	-43	-52	-52	-2	-11	-19	-19
Colby, Kans.....	30	-21	-28	-40	-44				
Hays, Kans.....	30	-25	-28	-42	-52				
Garden City, Kans.....	30	-32	-25	-46	-40				
Average of 3 locations.....	32	-34	-41	-51	-54	-3	-11	-21	-24
Average of all 7 locations...	32	-30	-34	-46	-49				

<sup>1</sup> The plots at Colby, Hays, and Garden City were sampled in 1916, and these values were used for determining percentage change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The majority of subsurface-soil samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6½ to 20 inches.

The carbon/nitrogen ratios of surface and subsurface soils under continuous and alternate cropping and fallow for small grains and row crops, at the beginning and at the end of the cropping period, are presented (table 12). The greater loss of carbon than of nitrogen is apparent in the carbon/nitrogen ratios. During the period, all ratios were reduced in the surface soil, and most of them in the subsurface soil. There was less reduction in the lower depth than in the upper. The greatest reduction occurred under row crops alternating with fallow.



TABLE 12.—Carbon/nitrogen ratios of surface and subsurface soils under continuous and alternate cropping and fallow for small grains and row crops, at the beginning<sup>1</sup> and at the end of the cropping period, at 7 locations in the Great Plains

## SURFACE SOILS:

Location	Years of cropping	Small grains				Row crops			
		Continuous cropping		Alternate fallow		Continuous cropping		Alternate fallow	
		Begin-ning	End	Begin-ning	End	Begin-ning	End	Begin-ning	End
	<i>Number</i>								
Mandan, N. Dak.....	30	13.1	12.6	13.1	12.6	13.2	12.5	13.2	12.3
Havre, Mont.....	31	11.6	9.6	11.6	9.1	11.6	8.8	11.6	8.7
Sheridan, Wyo.....	30	10.3	9.5	10.0	9.9	10.3	9.3	10.4	9.0
Archer, Wyo.....	34	10.9	9.7	10.9	9.4	10.9	8.9	10.9	8.9
Colby, Kans.....	30	11.4	9.8	10.7	10.3	11.5	9.8	11.0	8.2
Hays, Kans.....	30	11.7	9.8	11.7	10.0	11.8	10.2	12.5	9.8
Graden City, Kans.....	30	11.9	9.0	10.9	9.4	11.1	8.3	11.0	9.0
Average.....	31	11.6	10.0	11.3	10.1	11.5	9.7	11.5	9.4

## SUBSURFACE SOILS:

Mandan, N. Dak.....	30	12.6	12.5	12.5	12.6	12.6	12.0	12.4	12.2
Harve, Mont.....	31	9.2	9.4	9.2	9.0	9.2	8.8	9.2	8.8
Archer, Wyo.....	34	9.3	9.1	9.3	8.8	9.3	8.6	9.3	8.5
Average.....	32	10.4	10.3	10.3	10.1	10.4	9.8	10.3	9.8

<sup>1</sup> Carbon/nitrogen ratios for Mandan, Havre, and Archer for the beginning of the period are based on samples collected from virgin sod at end of the period and are assumed to be the same as at the beginning of the period.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6½ to 20 inches.

## Barnyard Manure Versus No Manure

The effect of barnyard manure in a rotation on the loss of nitrogen and organic carbon from the soil, as compared with a similar rotation without manure, is presented (table 13).

The rotations were 2-, 3-, or 4-year rotations. Manure was applied to 1 plot in a rotation each year. That is, a given plot in a 2-year rotation would receive manure every 2 years; in a 3-year rotation, a given plot would receive manure every 3 years; and so on. The average annual rate of application for a given plot ranged from approximately 2½ to 5 tons of barnyard manure per acre. This amounted to approximately 25 to 50 pounds of nitrogen per acre annually.

The data presented show that the application of manure reduced the loss of nitrogen and carbon at all locations and in both depths. At some locations the benefit from manure was only slight, while at others it was considerable. Both nitrogen and carbon data were available for both treatments and depths at only 5 of the 12 locations. The mean loss of nitrogen from the surface soils at these 5 locations was 33 percent from the rotation without manure and 14 percent from the rotation with manure. For the subsurface soils, the values were 14 and 7 percent, respectively. The average loss of organic carbon at those same 5 stations was 39 percent from the rotation without manure and 19 percent from the rotation with manure for the surface soils. For the subsurface soils, the values were 15 and 8 percent, respectively. Although the loss of

nitrogen from the manured rotations has been approximately one-half that of the rotations without manure, total crop removal from the former has been only 11 percent greater.

TABLE 13.—*Percentage change in nitrogen and organic carbon of surface and subsurface soils,<sup>1</sup> compared with virgin sod,<sup>2</sup> in rotations with and without manure at 12 locations in the Great Plains*

Location	Years of cropping <sup>3</sup>	Total nitrogen				Organic carbon			
		Surface soils		Subsurface soils		Surface soils		Subsurface soils	
		With-out manure	With manure	With-out manure	With manure	With-out manure	With manure	With-out manure	With manure
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Mandan, N. Dak.....	30	-31	-4	-13	+7	-35	-9	-12	+7
Dickinson, N. Dak.....	40	-49	-39	-30	-10	-----	-----	-----	-----
Havre, Mont.....	31	-43	-32	-20	-18	-53	-43	-21	-17
Moccasin, Mont.....	39	-32	-21	-----	-----	-----	-----	-----	-----
Sheridan, Wyo.....	30	-26	+6	-9	-10	-30	+8	-10	-8
Archer, Wyo.....	34	-34	-19	-6	+2	-41	-27	-6	-2
Akron, Colo.....	39	-38	-22	-8	+3	-----	-----	-----	-----
Colby, Kans.....	30	-24	-16	-----	-----	-30	-26	-----	-----
Hays, Kans.....	30	-32	-29	-----	-----	-37	-33	-----	-----
Woodard, Okla.....	33	-53	-50	-----	-----	-----	-----	-----	-----
Lawton, Okla.....	31	-52	-48	-20	-19	-----	-----	-----	-----
Dalhart, Tex.....	39	-31	-22	-20	-17	-38	-25	-25	-18
Average of all 12 locations.....	34	-37	-25	-----	-----	-----	-----	-----	-----
Average of 5 locations.....	33	-33	-14	-14	-7	-39	-19	-15	-8
Average of 8 locations.....	34	-38	-22	-16	-8	-----	-----	-----	-----

<sup>1</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The values at Woodward are for the 0- to 12-inch depth. The majority of the subsurface samples were taken at depths from 6 or 7 to 12 inches. At Sheridan, the depth was 6 3/4 to 20 inches.

<sup>2</sup> The plots at Colby and Hays were sampled in 1916, and these values were used for determining percentage change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>3</sup> The cropping period began with the year the land was broken except at the Kansas stations. Manure was applied during the entire cropping period shown at all stations, except Akron where it was applied 23 years, Woodward where it was applied 28 years, Lawton where it was applied 28 years, and Dalhart where it was applied 33 years.

Sheridan was the only station where the manure increased the nitrogen and carbon contents of the surface soil above the increase for virgin sod. At Mandan, there was only a slight reduction in these elements where manure was applied. The nitrogen content of the subsurface soil was increased slightly at 3 of the locations where manure was applied. Brage and coworkers (6) pointed out that numerous investigators reported difficulty in increasing the nitrogen or carbon content of the soil by applications of barnyard manure. In the study in Minnesota, however, they showed that where manure had been applied to a 4-year rotation over a period of 30 years at different rates, the nitrogen content of the soil was progressively higher than the check treatment with each additional increment of manure applied.

The quantity of nitrogen in the manure should have been sufficient to meet the needs of the crops. It is therefore apparent that considerable nitrogen has been lost by means other than crop removal. As mentioned earlier, Lyon (28) stated that the application of large quantities of manure may contribute to losses of nitrogen in the gaseous form. The rates of application were not excessive, but these amounts on soils that had been broken from sod for a relatively short time may have been

sufficient for volatilization to occur. Russell (38, *pp.* 299-300) states that where much organic matter occurs, as in soils heavily manured or in certain virgin soils, it is difficult to account for the lost nitrogen. It was assumed that part of the nitrogen was lost as gas during oxidation of organic matter.

It is possible that volatilization may have accounted for some loss of nitrogen from manured land. Leaching from the depth of sampling may also have been a factor; but inasmuch as little of the nitrogen at this level would have been lost from the root zone, most of it was still available for plant use. Wind and water erosion may account for nitrogen losses in some instances.

The carbon/nitrogen ratios at the beginning and at the end of the cropping periods, for soils in rotations with and without manure, are presented (table 14). In the surface soils, the ratios were reduced at every location in both treatments. In the subsurface soils, the ratios were reduced at some locations and increased at others. The average ratio of the surface soils for 5 of the locations was reduced approximately 1.0 by cropping, whereas the average ratio for the subsurface soils was only reduced approximately 0.1 or 0.2. The carbon/nitrogen ratio at the end of the period was usually only slightly higher under the manured rotation than under the rotation without manure.

TABLE 14.—Carbon/nitrogen ratios of surface and subsurface soils, at the beginning<sup>1</sup> and at the end of the cropping period, for rotations with and without manure, at 7 locations in the Great Plains

Location	Years of cropping	Surface soils <sup>2</sup>				Subsurface soils <sup>2</sup>			
		Without manure		With manure		Without manure		With manure	
		Begin-ning	End	Begin-ning	End	Begin-ning	End	Begin-ning	End
	<i>Number</i>								
Mandan, N. Dak.-----	30	13.1	12.4	13.2	12.5	12.5	12.6	12.5	12.6
Havre, Mont.-----	31	11.6	9.6	11.6	9.8	9.2	9.1	9.2	9.2
Sheridan, Wyo.-----	30	10.4	9.9	10.5	10.7	10.3	10.3	10.2	10.4
Archer, Wyo.-----	34	10.9	9.7	10.9	9.8	9.3	9.2	9.3	8.9
Colby, Kans.-----	30	10.1	9.3	10.6	9.4	-----	-----	-----	-----
Hays, Kans.-----	30	10.6	9.8	10.7	10.1	-----	-----	-----	-----
Dalhart, Tex.-----	39	10.9	9.9	10.9	10.4	10.2	9.5	10.2	10.0
Average of all 7 locations..	32	11.1	10.1	11.2	10.4	-----	-----	-----	-----
Average of 5.-----	33	11.4	10.3	11.4	10.6	10.3	10.1	10.3	10.2

<sup>1</sup> Carbon/nitrogen ratios for Mandan, Havre, Archer, and Dalhart for the beginning of the period are based on samples collected from virgin sod at the end of the period and are assumed to be the same as at the beginning of the period.

<sup>2</sup> The majority of the surface soil samples were taken at depths from 0 to 6 or 7 inches. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6¾ to 20 inches.

## Effects of Green-Manure Crops on Soil Nitrogen and Carbon

The percentage change in nitrogen and carbon content of the surface and subsurface soils, in rotations with and without green manure, is presented (tables 15 and 16, respectively). The carbon/nitrogen ratios at the beginning and at the end of the period are presented (table 17). In these investigations, 2-, 3-, or 4-year rotations were used, the 4-year rotation being predominant. The legumes used were sweetclover, cowpeas, or field peas; these were usually plowed in spring or early summer and fallowed the remainder of the season.

TABLE 15.—*Percentage change in nitrogen of surface and subsurface soils compared with virgin sod,<sup>1</sup> in rotations with and without green manure, at 13 locations in the Great Plains*

Location	Years of cropping <sup>2</sup>	Surface soils <sup>3</sup>			Subsurface soils <sup>3</sup>		
		No green manure	Rye, green manure	Legume, green manure	No green manure	Rye, green manure	Legume, green manure
	<i>Number</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Mandan, N. Dak.....	30	-31	-32	-30	-13	-13	-8
Dickinson, N. Dak.....	40	-50	-48	-50	-37	-31	-35
Havre, Mont.....	31	-37	-36	-	-15	-6	-
Moccasin, Mont.....	39	-32	-	-32	-	-	-
Sheridan, Wyo.....	30	-21	-18	-19	-10	-6	-7
Archer, Wyo.....	34	-34	-30	-33	-6	-4	-6
Akron, Colo.....	39	-37	-37	-33	-8	-8	-3
Colby, Kans.....	30	-28	-27	-30	-	-	-
Hays, Kans.....	30	-18	-14	-17	-	-	-
Garden City, Kans.....	30	-18	-22	-	-	-	-
Garden City, Kans., Annex.....	15	-25	-25	-24	-	-	-
Woodward, Okla.....	33	-62	-	-61	-	-	-
Lawton, Okla.....	31	-48	-	-47	-12	-	-16
Average of 8 locations.....	31	-30	-29	-30	-	-	-
Average of 5 locations.....	35	-35	-33	-33	-15	-12	-12

<sup>1</sup> The plots at Colby, Hays, and Garden City, Kans., were sampled in 1916, and these values were used for determining percentage change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>2</sup> The green manure rotations were in effect for the entire cropping period at all stations except Woodward where they were in effect for 29 years, and Lawton where they were in effect for 28 years.

<sup>3</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The values at Woodward are for the 0- to 12-inch depth. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6½ to 20 inches.

<sup>4</sup> For the first 20 years, the area occupied by this rotation was in a rotation in which peas were plowed under for green manure.

TABLE 16.—*Percentage change in organic carbon in surface and subsurface soils compared with virgin sod,<sup>1</sup> in rotations with and without green manure, at 8 locations in the Great Plains*

Location	Years of cropping	Surface soils <sup>3</sup>			Subsurface soils <sup>3</sup>		
		No green manure	Rye, green manure	Legume, green manure	No green manure	Rye, green manure	Legume, green manure
	<i>Number</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Mandan, N. Dak.....	30	-33	-36	-33	-11	-14	-10
Havre, Mont.....	31	-50	-51	-	-16	-12	-
Sheridan, Wyo.....	30	-24	-22	-26	-9	-7	-9
Archer, Wyo.....	34	-41	-40	-40	-6	-8	-7
Colby, Kans.....	30	-37	-34	-43	-	-	-
Hays, Kans.....	30	-30	-29	-29	-	-	-
Garden City, Kans.....	30	-32	-35	-	-	-	-
Garden City, Kans., Annex.....	15	-31	-30	-35	-	-	-
Average of 6 locations.....	28	-33	-32	-34	-	-	-
Average of 3 locations.....	31	-33	-33	-33	-9	-10	-9

<sup>1</sup> The plots at Colby, Hays, and Garden City, Kans., were sampled in 1916, and these values were used for determining percentage change for the period 1916-46. The land had been cropped for several years prior to 1916. All other values are based on virgin sod.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6½ to 20 inches.

The data show that neither rye with green manure nor legume with green manure were effective in reducing the losses of nitrogen and carbon. Carbon/nitrogen ratios in the green-manure rotations were approximately

the same as in rotations without green manure. At Sheridan, Wyo. (see appendix table 34), 1 plot had been grown continuously to peas for a 30-year period. All the crop was plowed under for green manure each year. The soil from this plot lost 28 percent of its nitrogen, which was as high as from row-crop and small-grain rotations where the crops had been removed. Wind and water erosion, however, was a problem on this plot, which probably would account for some of the loss.

TABLE 17.—Carbon/nitrogen ratios of surface and subsurface soils, at the beginning<sup>1</sup> and at the end of the cropping period, for rotations with and without green manure at 8 locations in the Great Plains

Location	Years of cropping	Surface soils <sup>2</sup>						Subsurface soils <sup>2</sup>					
		No green manure		Rye, green manure		Legume, green manure		No green manure		Rye, green manure		Legume, green manure	
		Begin-ning	End	Begin-ning	End	Begin-ning	End	Begin-ning	End	Begin-ning	End	Begin-ning	End
	Number												
Mandan, N. Dak.	30	13.1	12.6	13.2	12.4	13.1	12.5	12.5	12.9	12.6	12.5	12.6	12.3
Havre, Mont.	31	11.6	9.3	11.6	8.9	-----	-----	9.1	8.7	9.1	8.5	-----	-----
Sheridan, Wyo.	30	10.3	9.9	10.6	10.1	10.3	9.4	10.0	10.1	10.0	9.9	10.1	9.9
Archer, Wyo.	34	10.9	9.7	10.9	9.4	10.9	9.8	9.3	9.2	9.3	8.9	9.3	9.2
Colby, Kans.	30	11.3	9.8	10.7	9.8	11.5	9.3	-----	-----	-----	-----	-----	-----
Hays, Kans.	30	10.8	9.2	11.9	9.8	11.3	9.6	-----	-----	-----	-----	-----	-----
Garden City, Kans.	30	11.6	9.8	11.1	9.2	-----	-----	-----	-----	-----	-----	-----	-----
Garden City, Kans., Annex.	15	9.9	9.1	10.1	9.4	10.3	8.9	-----	-----	-----	-----	-----	-----
Average of 6 locations	28	11.0	10.0	11.2	10.2	11.2	9.9	-----	-----	-----	-----	-----	-----
Average of 3 locations	31	11.4	10.7	11.6	10.6	11.4	10.6	10.6	10.7	10.6	10.4	10.7	10.5

<sup>1</sup> Carbon/nitrogen ratios for Mandan, Havre, and Archer for the beginning of the period are based on samples collected from virgin sod at the end of the period, and are assumed to be the same as at the beginning of the period.

<sup>2</sup> The majority of the surface soil samples were taken at depths from 0 to 6 or 7 inches. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6½ to 20 inches.

These results are, in general, contrary to those obtained in more humid regions. Tidmore and Volk (46), working in Alabama, reported that at the end of a 9-year period, soils on which legumes were plowed under contained about 30 percent more nitrogen than soils that received no legumes. The nitrogen content of the nontreated plot was 0.035 percent.

Jones (26), also working with soils in Alabama, found that growing vetch on the Hartsells and Decatur soils resulted, respectively, in net annual gains of 66 pounds and 52 pounds of nitrogen per acre. When vetch was grown following fall-turned soybeans, the annual net gain in nitrogen amounted to 43 pounds on Norfolk, 66 pounds on Hartsells, and 104 pounds on Decatur soil. The nitrogen content of these soils was 0.019, 0.039, and 0.078 percent, respectively. Chapman and Liebig (10), working in California with purple vetch and annual yellow sweetclover in lysimeters, reported that over a 10-year period there had been a net unaccounted-for gain of over 100 pounds of nitrogen per acre where these legumes had been plowed under as green manure.

Greaves and Jones (20), working with legumes grown in jars over a 16-year period in Utah, found that where the legume was removed, no

gains in soil nitrogen were obtained; but if the legume crop was plowed under, appreciable gains resulted.

Greaves and Bracken (19) reported results from Nephi, Utah, which showed that peas in rotation with wheat tended to maintain the nitrogen content of the soil over a 25-year period.

Lyon and Wilson (29), working at the Agricultural Experiment Station of Cornell University, found that where various legumes and nonlegumes were plowed under each year over an 11-year period, the vetch plots lost 42 pounds of nitrogen per acre; the rye plots, 217 pounds per acre; the plots planted to peas, 380 pounds per acre; the oats plots, 382 pounds per acre; and the buckwheat plots, 412 pounds per acre. This would indicate that rye was more effective than peas in reducing nitrogen losses.

The question may logically be raised as to why results from the Great Plains are contrary to those from other regions. There are several possible reasons for this discrepancy: (1) Moisture is generally limited in the Great Plains, and nitrogen may not be fixed by the symbiotic organisms as readily under this condition. Satisfactory stands of green-manure crops are not always obtained; this is especially true of sweet-clover. Furthermore, the growth and development of the root system may be restricted under dryland conditions which might influence the fixation of nitrogen. (2) Inasmuch as these soils have been broken from sod for a comparatively short time, it is possible that the organisms may be able to obtain their nitrogen requirements from the soil and do not need to fix nitrogen from the air. (3) Nitrogen that has been fixed by the organisms may have been leached below the depth of sampling. (4) Nitrogen may have been fixed by the organisms, but lost by volatilization during the fallow period following the plowing under of the green manure. (5) Nitrogen may have been fixed, but the crops removed following the green-manure rotation may have contained a higher percentage of nitrogen. In general, green manure has not increased the yield of crops which follow, but the total pounds of nitrogen per acre removed in the crops may have been greater.

The results obtained in this study indicate that green manures have been of little or no value in reducing the loss of nitrogen under dryland conditions in the Great Plains. These results also suggest the need for further study of this problem to determine why greater benefit has not been received from the use of green-manure crops.

### Effects of Grass and Alfalfa on Nitrogen and Carbon Changes

The percentage change in the nitrogen and carbon content of the surface and subsurface soils of rotations with or without grass or alfalfa are presented (table 18). The corresponding carbon/nitrogen ratios are also presented (table 19).

The grass or alfalfa rotations contained 6 plots each. Of these plots, 3 were in grass or alfalfa, and 3 were in a rotation of corn, wheat, oats.

Until 1937, 1 plot of grass or alfalfa was broken each year, and 1 of the annual crop plots was seeded to grass or alfalfa each year. The annual crop rotation was moved 1 plot each year, to include the plot that had been broken from sod. By this system, a specified plot was in grass or alfalfa for 3 years.

In 1937, the rotations at some of the stations were changed to a deterred type in which a sod plot was plowed every 4 years. Thus, the grass or alfalfa remained on a given plot for 12 years.

The rotation without grass or alfalfa was a 3-year rotation of corn, wheat, oats. The crops were harvested and removed from the land in each rotation.

TABLE 18.—Percentage change in nitrogen and organic carbon in surface and subsurface soils compared with virgin sod, in rotations with and without grass or alfalfa, at 4 locations in the Great Plains

Location	NITROGEN						
	Surface soils <sup>1</sup>				Subsurface soils <sup>1</sup>		
	Years of cropping	Rotation without grass or alfalfa	Grass and grain-crop rotation	Alfalfa and grain-crop rotation	Rotation without grass or alfalfa	Grass and grain-crop rotation	Alfalfa and grain-crop rotation
	Number	Percent	Percent	Percent	Percent	Percent	Percent
Mandan, N. Dak.....	30	-31	-25	-18	-13	-6	+3
Dickinson, N. Dak.....	40	-49	-44	-44	-30	-	-31
Sheridan, Wyo.....	30	-27	-13	-18	-10	-8	-5
Archer, Wyo.....	34	-34	-30	-35	-6	-3	-9
Average of 3 locations....	31	-31	-23	-24	-10	-6	-4

ORGANIC CARBON							
Mandan, N. Dak.....	30	-36	-29	-24	-13	-8	+3
Sheridan, Wyo.....	30	-31	-20	-26	-10	-	-
Archer, Wyo.....	34	-41	-38	-44	-6	-4	-8
Average of 2 locations....	32	-38	-34	-34	-10	-6	-2

<sup>1</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan the depth was 6½ to 20 inches.

The data presented indicate that the grass or alfalfa rotations reduced the loss of nitrogen and carbon at Mandan and Sheridan but had little effect at the other stations. At Sheridan and Archer, there was less loss of nitrogen from the grass rotation than from the alfalfa rotation. This is difficult to explain unless it is because the amount of nitrogen removed by crops in the alfalfa rotation was considerably greater than in the grass rotations. At Mandan, the alfalfa rotation was more effective in reducing the loss of nitrogen than was the grass rotation, and the total amount of crop removed was greater. The nitrogen content of the crops was not determined, but it is assumed that the amount of nitrogen removed in the crops would have been greater in the alfalfa rotation. It would appear, then, that the alfalfa is adding nitrogen to the soil at Mandan, but not in sufficient quantities to maintain the soil at its original level.

The greater loss of carbon than of nitrogen is reflected in the decrease in the carbon/nitrogen ratio from the beginning to the end of the cropping period in the surface soils. The ratios at the end of the period for the grass and alfalfa rotations were approximately the same as for the rotation without these crops. Cropping had little effect on the C/N ratio in the subsurface soils, but the ratio was slightly higher in the alfalfa rotation than in the others at the end of the period.

TABLE 19.—Carbon/nitrogen ratios of surface and subsurface soils, at the beginning<sup>1</sup> and at the end of the cropping period, for rotations with and without grass or alfalfa, at 3 locations in the Great PlainsSURFACE SOILS<sup>2</sup>

Location	Years of cropping	Rotation without grass or alfalfa		Grass- and grain-crop rotation		Alfalfa and grain-crop rotation	
		Begin-ning	End	Begin-ning	End	Begin-ning	End
	<i>Number</i>						
Mandan, N. Dak.-----	30	13.1	12.3	13.2	12.5	13.2	12.3
Sheridan, Wyo.-----	30	10.5	9.9	10.8	9.9	10.6	9.5
Archer, Wyo.-----	34	10.9	9.7	10.9	9.6	10.9	9.5
Average of all 3 locations..	31	11.5	10.6	11.6	10.7	11.6	10.4

SUBSURFACE SOILS<sup>2</sup>

Mandan, N. Dak.-----	30	12.5	12.5	12.5	12.3	12.5	12.6
Sheridan, Wyo.-----	30	10.4	10.4	-----	10.0	-----	10.0
Archer, Wyo.-----	34	9.3	9.2	9.3	9.3	9.3	9.4
Average of 2 locations....	32	10.9	10.8	10.9	10.8	10.9	11.0

<sup>1</sup> Carbon/nitrogen ratios for Mandan and Archer for the beginning of the period are based on samples collected from virgin sod at the end of the period and are assumed to be the same as at the beginning of the period.

<sup>2</sup> The majority of the surface-soil samples were taken at depths from 0 to 6 or 7 inches. The majority of the subsurface samples were taken from 6 or 7 to 12 inches. At Sheridan, the depth was 6¾ to 20 inches.

The number of locations having grass or alfalfa rotations was so limited, and the results so variable, that it is difficult to draw definite conclusions.

It is apparent, however, that neither grass nor alfalfa grown in rotation with annual crops was able to maintain the nitrogen or carbon content of the soil at the same level as virgin sod. In fact, the losses from these rotations were substantially the same as from plots continually cropped to small grains. (Compare table 18 with table 10.) Grass grown continuously on the same soil would be expected to maintain the nitrogen at a level approximately equal to that at the time the grass was seeded; but where annual grain crops are rotated with the grass, a decline in nitrogen would be expected. McHenry and coworkers (30), working at North Platte, Nebr., with grass stands ranging in age from 1 to 9 years, found that losses of nitrogen occurred in all plots except one. Those plots which had been in grass more than 6 years out of the 9 contained significantly more nitrogen than those which had been in continuous cultivation, although they had actually lost some of their original nitrogen.

Results at Mandan, N. Dak.,<sup>7</sup> showed that the nitrogen content of the surface 6 inches of soil, which had been in grass for 6 years, was approximately the same as at the time it was seeded to grass. Land which had been cropped to corn and wheat during that period lost 6 percent of its nitrogen.

Thus, since annual crops were rotated with grass in those rotations reported upon (table 18), the results are not too surprising. It was expected, however, that alfalfa in rotation with annual crops would ma-

<sup>7</sup> Unpublished experimental data on file at United States Northern Great Plains Field station, Mandan, N. Dak.



terially reduce the loss of nitrogen and carbon. Bracken and Larson (5), working in Utah, reported that where alfalfa was grown in rotation with wheat, the nitrogen content of the soil was maintained at a level approximately 7 percent below that of virgin sod.

Earlier work by Stewart (43), on selected Utah farms, showed that alfalfa caused a decrease in the nitrogen content of the soil compared to that of virgin soil, whereas wheat continuously cropped, or alternately cropped and fallowed, did not decrease the nitrogen content of the surface foot of the soil.

Atkinson and Wright (4) reported results from Ottawa, Canada, which showed that land which had been in grass with some alfalfa for 15 years increased in soil nitrogen, while that under cultivation lost nitrogen.

Greaves and Jones (20), working with a Utah soil in jars, found that the growth of alfalfa on this soil for 16 years and the removal of the crop did not measurably increase the total nitrogen content. Where the crop was returned to the soil, a highly significant gain in soil nitrogen resulted. They state that "probably there is a certain nitrogen balance in some soils below which legumes may increase the soil nitrogen even where the complete crop is removed; for this soil it is undoubtedly below 0.105 percent."

## Soil Nitrogen in Relation to Nitrification Rate and Uptake of Nitrogen by Plants

### Laboratory Studies

In 1947, Allison and Sterling (2) conducted a study in which they used soils from the rotation plots at Mandan, N. Dak., to determine whether nitrate formation in a soil is markedly influenced by past cropping and cultural practices or, on the other hand, is largely independent of such treatments but correlated closely with total soil nitrogen. They concluded: "In a given soil type and under like climatic conditions, thoroughly humified soil organic matter is fairly uniform in quality regardless of past agronomic treatment. The total nitrogen content under these conditions appears to be a rough index of the nitrate-furnishing powers of variously treated soils."

Earlier work done by such investigators as Gainey (17) and Fraps (15) showed a relationship between the nitrogen content of the soil and its ability to produce nitrate. Fraps and Steiges (16) listed several factors which affected the nitrifying capacity of the soil. Waksman (48) showed a definite relationship between the nitrifying capacity of the soil and crop productivity. Albrecht (1), working with soils in Missouri, found that nitrate production of a soil decreased rapidly with cropping, and that at the end of a 13-year period it had declined as much as 50 percent.

To obtain further information on this problem, studies were undertaken in 1950 to determine the relationship of total nitrogen and nitrate production in soils that varied widely as to type and total nitrogen content. Soil samples were collected from selected rotation plots at 13 experimental stations in the Great Plains, which had been cropped for 30 years or more. Where possible, 1 row-crop plot and 1 small-grain plot were sampled from each rotation; in the instance of alternate crop and fallow, both the cropped and the fallow plots were sampled. In

most instances, sampling was done as soon as possible after harvest of each crop.

From 8 to 12 samples were collected at the 0- to 6-inch depth from 9 of the stations, and from 27 to 33 samples were collected at 4 stations. These samples were incubated in a constant-temperature room at Mandan, N. Dak., by the procedure described earlier in this publication (p. 6).

### *Relationship of Total Nitrogen in the Soil and Nitrate Production During a 6-Week Incubation Period*

The total nitrogen percentage of the soils studied and the parts per million of nitrate-nitrogen produced during a 6-week incubation period are presented (appendix tables 45 and 46). The correlation coefficient and regression equation for each location were computed to show the relationship between the total nitrogen percentage of the soil and the ability of the soil to produce nitrate. These values are presented (table 20).

TABLE 20.—*Correlation coefficients and regression equations showing the relationship of the total nitrogen percentage ( $X$ ) of the 0- to 6-inch depth of soil and the nitrate-nitrogen expressed in parts per million ( $Y$ ) produced during a 6-week incubation period*

Location	Number of samples	Correlation coefficient ( $r$ ) <sup>1</sup>	Regression equation
Havre, Mont. ....	11	0.610*	$Y=270.71X+4.9$
Moccasin, Mont. ....	29	.791**	$Y=229.41X-7.4$
Huntley, Mont. ....	10	.779**	$Y=311.97X-8.7$
Sheridan, Wyo. ....	11	.841**	$Y=401.09X-0.1$
Archer, Wyo. ....	7	.881**	$Y=534.16X+0.2$
Newell, S. Dak. ....	12	.982**	$Y=473.48X-29.9$
North Platte, Nebr. ....	12	.956**	$Y=348.68X-1.1$
Akron, Colo. ....	29	.736**	$Y=362.14X+2.1$
Colby, Kans. ....	11	.816**	$Y=406.26X-7.5$
Hays Kans. ....	33	.564**	$Y=313.73X+5.6$
Garden City, Kans. ....	10	.338NS	$Y=540.04X+18.2$
Dalhart, Tex. ....	11	.441NS	$Y=320.51X+4.8$
Big Spring, Tex. ....	27	.933**	$Y=369.92X-1.4$
All 13 locations. ....	213	.562**	$Y=166.15X+15.4$

<sup>1</sup> 1 asterisk (\*) indicates significant at 5-percent level; 2 asterisks (\*\*) indicate significant at 1-percent level; NS indicates nonsignificant.

The correlation coefficient was significant at the 1-percent level at each location except Havre., Mont., where it was significant at the 5-percent level; and Garden City, Kans., and Dalhart, Tex., where it was non-significant. Too much confidence should not be placed in the data at those locations where only 8 to 12 samples were collected, but these data do indicate that there was a definite relationship between the 2 variables at most locations.

However, nitrogen and other factors that were controlled during incubation are not the only factors that may affect nitrification. For example, although the correlation coefficient ( $r$ ) at Hays tested highly significant,  $r^2$  was only 0.307. This indicates that only about 31 percent of the variation in nitrate production among the soils was associated with total nitrogen. Inasmuch as phosphorus and calcium carbonate were added, neither phosphorus nor high acidity should have been limiting.

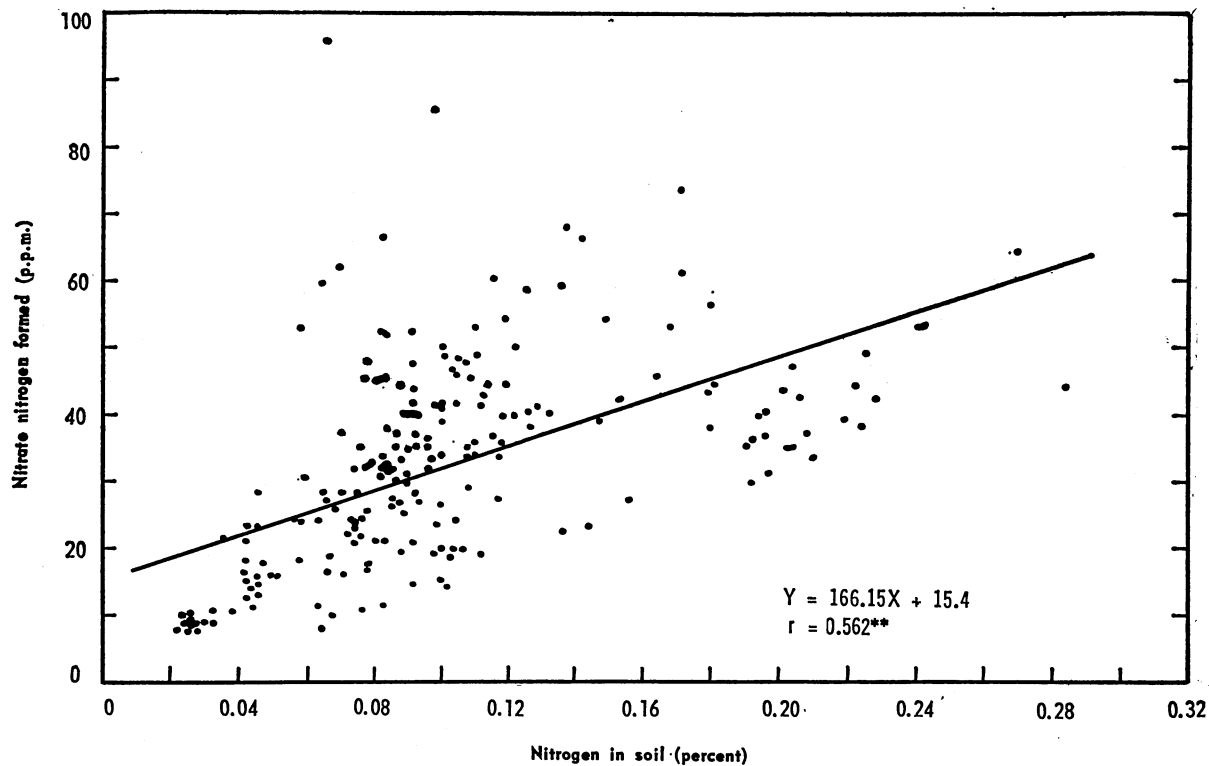


FIGURE 5.—Regression of nitrate-nitrogen formed during a 6-week incubation period on the total nitrogen percentage of the soil from all stations studied. (The 2 asterisks (\*\*) indicate significant at 1-percent level.)

The carbon/nitrogen ratio may have been a factor, but carbon was not determined on those particular samples.

It was also noted that at some locations the virgin-sod samples did not produce as much nitrate-nitrogen in relation to their nitrogen content as did the cropped soils. As discussed in a previous section of this publication (p. 12), virgin-sod samples had a higher carbon/nitrogen ratio than did cropped soils. This might well account for a temporary depression in nitrification rate.

The regression coefficients showed that the increase in nitrate production for each increase in percent total nitrogen varied considerably among locations. Thus, the influence which total nitrogen had on nitrate production depended somewhat on soil type. Possibly the quality of the organic matter varied among soil types in such a way as to influence nitrification, but no determinations were made of the quality of organic matter.

Soil texture and structure may have also influenced nitrification indirectly by their effect on aeration, although the samples were shaken periodically to increase aeration as much as possible.

To determine the relationship of nitrate production to total nitrogen during the 6-week incubation period, the data from all locations were grouped together and the linear regression was computed. These data are plotted and the regression line is shown (fig. 5). Although the correlation coefficient was significant at the 1-percent level, the points were rather widely separated. The square of the coefficient would indicate an association of about 32 percent.

The points were too numerous to attempt to differentiate between locations, but there were 2 locations which were of considerable interest—Garden City, Kans., and Moccasin, Mont. The data from 6 of the samples from Garden City are shown in the upper left-hand side of the chart, while Moccasin is represented by the numerous points in the lower right-hand side. Surprisingly, most of the samples from Garden City produced fairly large quantities of nitrate, even though the nitrogen content of the soil was below the group average. Most of the soils from Moccasin were higher in nitrogen than were soils from any of the other locations, yet the quantity of nitrate produced by these soils was comparatively low.

#### ***Relationship of Total Nitrogen in the Soil and Nitrate-Nitrogen Production During 6, 12, 18, and 24 Weeks of Incubation***

To determine the effects of incubation periods greater than 6 weeks on nitrate formation, 1 high- and 1 low-nitrogen soil from each location were incubated for 6, 12, 18, and 24 weeks. In most instances the high-nitrogen soil was that from virgin sod and the low-nitrogen soil from continuous row crop. Duplicate samples were incubated for each period. The nitrate-nitrogen produced during each period is given in parts per million (table 21).

It will be noted that in almost every instance, the greatest quantity of nitrate per 6-week period was produced during the first 6-week period. The exceptions were the high-nitrogen soils from Moccasin and the low-nitrogen soils from Colby. The average values showed that the rate of nitrification per 6-week period decreased with each succeeding period, but this was not true of all locations. In some instances, production

during the third 6-week period was greater than during the second; in other instances, production during the fourth period was greater than during the third. This may have been due to an error in laboratory or incubation procedures, or to some inherent property of the soil or some type of organic matter.

TABLE 21.—*Parts per million (p. p. m.) of nitrate-nitrogen produced by the 0- to 6-inch depth of high- and low-nitrogen soils from various stations during incubation periods of different length*

Station	Nitrogen in soil	Nitrate nitrogen produced during incubation for—			
		6 weeks	12 weeks	18 weeks	24 weeks
	<i>Percent</i>	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>
Havre, Mont.-----	.075	21.3	34.8	39.5	42.3
	.121	39.7	59.7	67.4	80.7
Moccasin, Mont.-----	.179	43.2	57.8	76.1	77.4
	.284	44.1	92.0	165.1	196.8
Huntley, Mont.-----	.076	10.7	15.4	25.6	28.6
	.088	19.2	30.1	47.8	48.6
Sheridan, Wyo.-----	.100	41.3	64.6	79.8	87.6
	.171	73.6	103.5	138.7	141.1
Archer, Wyo.-----	.077	30.3	39.8	58.4	60.7
	.116	60.1	87.0	99.1	112.7
Newell, S. Dak.-----	.101	14.1	23.6	29.6	33.2
	.164	45.8	80.7	105.7	113.9
North Platte, Nebr.-----	.074	22.6	36.0	44.0	53.1
	.180	56.7	101.6	131.9	143.2
Akron, Colo.-----	.066	27.1	34.6	44.1	46.8
	.126	38.1	68.4	78.3	95.9
Colby, Kans.-----	.071	16.1	25.1	30.4	47.7
	.153	42.3	71.8	97.7	118.6
Hays, Kans.-----	.094	27.0	37.0	47.3	53.6
	.181	44.4	83.0	97.3	106.4
Garden City, Kans.-----	.064	59.3	67.9	80.0	84.7
	.098	85.5	106.3	108.0	127.5
Dalhart, Tex.-----	.044	11.3	18.2	21.2	25.6
	.068	25.5	41.7	54.9	57.1
Big Spring, Tex.-----	.024	9.0	14.3	19.4	20.9
	.058	23.8	33.2	42.6	48.1
Average of low-nitrogen soils.-----	.080	25.6	36.1	45.8	50.9
Average of high-nitrogen soils.-----	.139	46.1	73.8	95.0	107.0
Correlation coefficients for total nitrogen versus nitrate-nitrogen <sup>1</sup> -----		.514**	.725**	.855**	.859**

<sup>1</sup> 2 asterisks (\*\*) indicate significant at 1-percent level.

Earlier in this publication (p. 33), mention was made of the Garden City soils, with a comparatively low total nitrogen content, as having the ability to produce large quantities of nitrate. It was also mentioned that the soils at Moccasin, by contrast, had a high total nitrogen content but produced much less nitrate. This was evident for the first 6-week period; but for longer periods, the soil at Garden City reacted in about the same way as did other soils of similar nitrogen content, and nitrate production was well below that of the soils at Moccasin.

The correlation coefficients showing the relationship between total nitrogen and nitrate-nitrogen production were highest for either the 18- or the 24-week incubation period. This would suggest that in order to obtain the maximum relationship between these 2 variables, the incubation period should have been greater than 12 weeks.

It will also be noted that the high-nitrogen soils at most of the locations maintained a higher level of production than did the low-nitrogen soils. This proves that high-nitrogen soils not only produce a greater quantity of nitrate, but are also able to maintain production over a longer

period of time (fig. 6). The data for this chart were obtained by separating the values shown in table 21 into 3 groups irrespective of location—those soils with low, medium, or high total soil-nitrogen content. The mean total nitrogen contents of the 3 groups of soils were 0.063, 0.106, and 0.187 percent, respectively.

For the high-nitrogen soils, the rate of nitrate production was much greater than for the other soils, and it declined only slightly during the

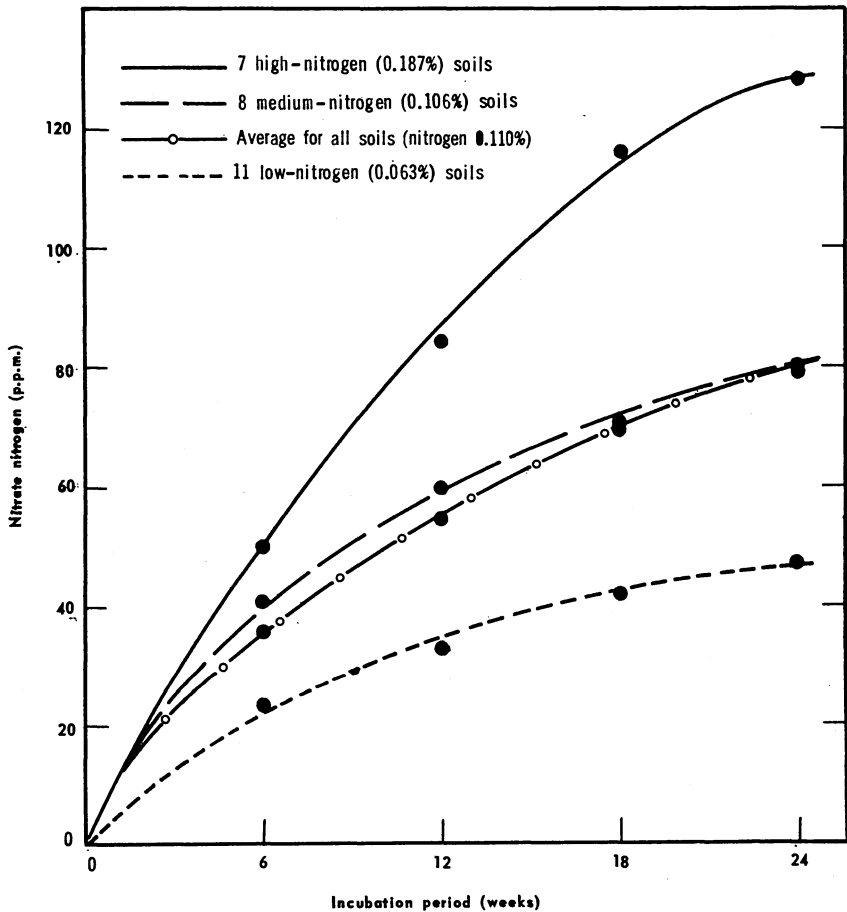


FIGURE 6.—Nitrate-nitrogen formation as influenced by length of incubation and nitrogen content of the soil.

12- and 18-week periods. During the 18- to 24-week periods, however, there was a sharp drop in production. The low-nitrogen soils produced approximately half the quantity of nitrate during the first 6-week period as did the high-nitrogen soils. After the first period, the rate of production declined considerably, and it was nearly uniform throughout the 3 remaining periods. The rate of nitrate production during the first 6-week period for the medium-nitrogen soils was high, but it declined after that time and closely approximated the average values for all soils.

*Allison and Sterling* (2) and *Carpenter and coworkers* (8) found that not only do high-nitrogen soils produce greater quantities of nitrate than do low-nitrogen soils, but they continue nitrate production over longer periods of time. The results of the present study are in agreement with their findings. *Allison and Sterling* also found that lime added to the soil during incubation increased nitrification to a greater extent on low-nitrogen soils than on high-nitrogen soils. It is possible that the differences shown (fig. 6) would have been greater if lime had not been added to these soils.

### *Nitrate-Nitrogen Production from Cropped Soils as Compared with That from Virgin Sod*

Since it was shown that cropping caused a marked decline in the total nitrogen content of several dryland soils, it appeared desirable to determine the effect of cropping on the ability of such soils to produce nitrate. The data from one rotation at each location were used, and these data were compared with the values obtained from virgin sod. The results are presented (table 22). Too much confidence should not be placed on the limited data obtained from each location, but the combined results from the various locations as a whole should at least be indicative.

TABLE 22.—*Percentage of total nitrogen in the 0- to 6-inch depth of virgin sod and cropped soil<sup>1</sup> at different locations in the Great Plains, the parts per million of nitrate nitrogen produced by these soils during a 6-week incubation period, and the percentage change<sup>2</sup> in total nitrogen and nitrate-nitrogen*

Location	Total nitrogen		Nitrate-nitrogen		Percent change <sup>2</sup>	
	Virgin soil	Cropped soil	Virgin soil	Cropped soil	Total nitrogen	Nitrate-nitrogen
	<i>Percent</i>	<i>Percent</i>	<i>P. p. m.</i>	<i>P. p. m.</i>		
Havre, Mont.....	0.121	0.083	39.7	33.0	-31	-17
Moccasin, Mont.....	.284	.194	44.1	36.0	-32	-18
Sheridan, Wyo.....	.171	.121	73.6	40.0	-29	-46
Archer, Wyo.....	.116	.072	60.1	34.5	-38	-43
Newell, S. Dak.....	.166	.103	49.3	19.1	-38	-61
North Platte, Nebr.....	.176	.080	58.8	28.4	-55	-52
Akron, Colo.....	.126	.089	38.1	33.4	-29	-12
Colby, Kans.....	.153	.087	42.3	36.3	-43	-14
Hays, Kans.....	.181	.098	44.4	34.0	-46	-23
Dalhart, Tex.....	.068	.042	25.5	19.6	-38	-23
Big Spring, Tex.....	.058	.026	23.8	9.4	-55	-60
Average.....	.147	.090	45.4	29.4	-39	-35

<sup>1</sup> Average of 2 plots from 1 rotation at each location.

<sup>2</sup> Calculated by dividing the difference between the virgin-sod and cropped-soil values by the virgin sod value, and multiplying by 100.

The loss of total nitrogen was more uniform between locations than that of nitrate-nitrogen. The former ranged from 29 to 55 percent, whereas the loss in nitrate production ranged from 12 to 61 percent. At some locations, cropping had influenced nitrification less than total nitrogen, while at other locations the reverse was true. The average values were remarkably similar, however, being -39 percent for total nitrogen and -35 percent for nitrate production. These results therefore indicate that not only was the total nitrogen content of the soils

reduced by an average of 39 percent, but the quantity of nitrate-nitrogen these soils are able to produce was also reduced by almost the same amount.

### *Effects of Previous Crop or Fallow on Nitrate Production*

It was thought that the type of crop growing on the land immediately prior to the time of sampling might influence nitrification during incubation. Since differences in total nitrogen content of the soil would influence the results, data were used only where the crops compared occurred in the same rotation. That is, in order to compare nitrification in soil from row-crop land with that from fallow, the data from the alternate row-crop and fallow plots were used. The same was true for comparing small-grain land and fallow. However, the immediate effects of row crops or fallow could not be compared with those of small grain or fallow because of differences in total nitrogen content of the soil. To get a direct comparison between row-crop and small-grain land, data from a rotation containing both crops were used. Even with these precautions, there was still variation in nitrogen content of the soil at some locations.

Data showing the influence of previous crop or fallow on nitrate-nitrogen production during a 6-week incubation period are presented (table 23), together with the total nitrogen content of the soils. The results were variable, but a portion of this variability may have resulted from differences in total nitrogen content of the soils compared. However, there was an indication that nitrate production was less after fallow than after the alternate crop. This was true for 8 out of 11 locations for the alternate row crop and fallow treatment, and for 7 out of 12 locations for the alternate small-grain and fallow treatment. The average value for fallow land was similar to that for the respective cropped land; these values, however, were influenced to some extent by the extreme differences in the results at Garden City, particularly in the instance of alternate row crop and fallow.

Crops growing on fallow land generally have a more abundant supply of nitrate than those growing on previously cropped land; but the results of this study suggest that this greater abundance of nitrate on fallow may result from the greater quantity of nitrate present at seeding time of the crop. After the crop has used this initial available nitrogen, the supply may be no greater, or possibly not as great, on fallow land as on cropped land.

The results from row-crop and small-grain land in a rotation also varied from location to location. At 6 of the locations, nitrate production was greater after row crops; at the other 6, it was greater after small grains. The average for small-grain land was greater than for row-crop land, but this value too was influenced by the extreme differences at Garden City. With the results from this location omitted, the average values would have been approximately the same.

In summarizing these results, it is apparent that nitrate production in incubated soils was lower from fallow samples than from cropped samples, from most locations; and except for a few instances, there was little difference in nitrate production between row-crop and small-grain land.



TABLE 23.—*Effects of previous crop or fallow on the parts per million (p. p. m.) of nitrate-nitrogen produced during a 6-week incubation period by the 0- and 6-inch depth of soil from different locations in the Great Plains in 1950, and the percentage total nitrogen content of these soils*

Location	Nitrate-nitrogen						Total nitrogen					
	Row crop and fallow		Small grain and fallow		Rotation		Row crop and fallow		Small grain and fallow		Rotation	
	Cropped land	Fallow land	Cropped land	Fallow land	Row crop	Small grain	Cropped land	Fallow land	Cropped land	Fallow land	Row crop	Small grain
	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
Havre, Mont. ....	28.3	24.2	21.2	20.5	33.7	32.3	0.070	0.073	0.083	0.091	0.082	0.084
Moccasin, Mont. ....	22.3	23.4	31.1	35.8	41.8	39.8	.136	.142	.197	.192	.214	.208
Huntley, Mont. ....	16.5	7.8	17.1	16.7	23.2	19.9	.066	.064	.078	.078	.099	.100
Sheridan, Wyo. ....	40.6	35.1	48.3	41.1	40.4	39.7	.100	.086	.105	.100	.126	.118
Archer, Wyo. ....	-----	-----	45.1	47.8	31.8	37.2	-----	-----	.083	.091	.074	.070
Newell, S. Dak. ....	11.3	14.7	19.9	19.3	18.4	19.8	.082	.091	.106	.098	.102	.104
North Platte, Nebr. ....	20.5	-----	31.8	-----	31.7	25.1	.074	.096	.096	.096	.082	.078
Akron, Colo. ....	24.2	18.1	35.1	24.3	31.6	34.7	.057	.057	.076	.076	.086	.089
Colby Kans. ....	11.4	9.9	33.9	38.9	37.9	34.7	.063	.068	.099	.100	.084	.090
Hays, Kans. ....	28.1	25.5	58.5	44.1	35.3	44.6	.075	.089	.125	.113	.113	.114
Garden City, Kans. ....	30.1	62.0	51.7	66.5	52.9	95.8	.059	.070	.083	.082	.058	.065
Dalhart, Tex. ....	14.0	10.3	22.8	28.3	18.4	20.8	.043	.038	.045	.046	.042	.042
Big Spring, Tex. ....	8.0	7.8	15.6	12.9	-----	-----	.026	.026	.045	.045	-----	-----
Average (10 locations) <sup>1</sup> .....	22.7	23.1	34.0	33.6	33.4	38.2	.075	.078	.100	.097	.101	.101

<sup>1</sup> Archer, North Platte, and Big Spring omitted.

## Field Studies

### Nitrogen Uptake by Wheat in Relation to Nitrogen Content of Soil

Carpenter and coworkers (8) reported on the field study conducted in 1948 at Mandan, N. Dak., in which they showed the relationship between the nitrogen taken up by wheat and the total nitrogen content of the soil. They found that the quantities of nitrogen in wheat plants at tillering, jointing, heading, and dough stages of growth were correlated with the nitrogen content of the top 6 inches of soil and, except at heading, with the 6- to 12-inch layer. The uptake of nitrogen on the low-nitrogen soils fell off rapidly after the wheat reached the heading stage while uptake continued on the high-nitrogen soils. High correlations were obtained between grain yield and the quantity of nitrogen in plants at all stages, with the amount in the plants at jointing giving the best estimate of yield. Although correlations significant at the 1-percent level were obtained between yield of grain and the nitrogen content of the soil for the 0- to 6-inch and the 6- to 12-inch depths, the relationships were not as close as those between yield and nitrogen uptake by plants.

As previously stated (p. 36), results were in close agreement with those obtained by Allison and Sterling (2), working with many of the same soils and using the incubation procedure. The similarity in conclusions from these two methods of study suggests that either procedure has merit. The field study, however, seems more subject to variation from adverse climatic conditions.

***Effects of Barnyard Manure on Nitrogen Content and Yield of Wheat During One Season at Several Locations***

It has been shown previously in this publication (p. 22) that the application of barnyard manure reduced the loss of soil nitrogen more than did a nonmanured cropping treatment, at every location where such a comparison could be made. To estimate the effects of manure on the uptake of nitrogen, wheat plants grown in a manured and a nonmanured rotation at each of 11 locations were analyzed for nitrogen content. Information so obtained should give an indication of the beneficial effects of manure on the liberation of available nitrogen in the soil.

Since early differences resulting from nutrients are often obscured by shortages of moisture before final yields are obtained, samples were collected at an early stage of growth. The work of DeTurk (11) indicated the probability that differences in available nutrients, brought about by manure, would be reflected in the composition of the wheat plants during the early growth stage.

In 1949, therefore, 100 wheat plants from a manured rotation and 100 from a nonmanured rotation were obtained from each of the 11 locations in the Great Plains. The plan was to clip the plants when they were from 6 to 8 inches tall, but this could not be done at some locations. Consequently, there was considerable variation in height and stage of growth of the plants received. The samples were dried at 65° C., and were ground, weighed, and analyzed for nitrogen.

The weight and the nitrogen content of the plant samples, as well as the grain yields obtained from the plots, are presented (table 24). The weight of 100 plants was greater on the manured plots than on the unmanured (check) plots at all locations except Havre and Archer. At these 2 locations, the samples were not collected until heading. It is possible that the results would have been different if they had been collected at an earlier stage of growth.

The effect of manure, expressed as percentage increase over the check plots, ranged from a decrease of 18 percent at Archer to an increase of 146 percent at Sheridan. Although there was a wide range in results, the data show that sizable increases in early growth were obtained on manured land at the majority of the locations. Both winter and spring wheat were sampled at North Platte; the former showed the greater response to manure. Samples from Hays included 2 rates of manure application—6 and 12 tons. The increase from the 12-ton rate was more than twice that from the 6-ton rate.

The weight of nitrogen in the 100 plants was increased at all locations by the use of manure, except at Archer where there was no difference in the results of the 2 treatments. The percentage increase over the check plots ranged from 0 at Archer to 211 percent for winter wheat at North Platte.

The percentage of nitrogen in the plants was increased by the use of manure at all locations except Mandan and Dickinson. The percentage increase over the check plots ranged from a reduction of 10 percent at Mandan to an increase of 40 percent at North Platte.

It is evident from these results that manure favorably influenced both the weight and nitrogen content of the immature wheat plants at the

TABLE 24.—*Weight and nitrogen content of immature wheat plants, and final grain yields, from manured and nonmanured (check) rotations, at 11 locations in the Great Plains. 1949*

[Grain yields for various periods at the different locations are given for comparative purposes]

Location	Rotation number	Treatment	Stage of growth at sampling	100 plants			Grain yields per acre		
				Weight	Nitrogen	Nitrogen	Period	Average yield	Yield for 1949 only
				<i>Grams</i>	<i>Grams</i>	<i>Percent</i>	<i>Years</i>	<i>Bushels</i>	<i>Bushels</i>
Mandan, N. Dak.....	{ 71 19	Manured.....	} Early jointing.....	{ 53.1 24.6	{ 1.55 .79	{ 2.91 3.22	} 1915-49	{ 18.8 15.3	{ 12.2 7.3
Percentage increase over check.....		Check.....		116	96	-10		23	67
Dickinson, N. Dak.....	{ 71 19	Manured.....	} Tillering.....	{ 23.4 12.1	{ 0.80 .42	{ 3.40 3.46	} 1924-49	{ 17.9 14.5	{ 12.0 8.5
Percentage increase over check.....		Check.....		93	90	-2		23	41
Havre, Mont.....	{ 71 19	Manured.....	} Headed.....	{ 164.5 172.0	{ 5.25 5.06	{ 3.19 2.94	} 1916-49	{ 10.1 10.5	{ 2.2 2.8
Percentage increase over check.....		Check.....		-4	4	8		-4	-21
Huntley, Mont.....	{ 69 13	Manured.....	} Early jointing.....	{ 58.8 46.0	{ 3.02 2.09	{ 5.13 4.55	} 1915-49	{ 12.3 13.4	{ 10.8 9.5
Percentage increase over check.....		Check.....		28	44	13		-8	14
Sheridan, Wyo.....	{ 71 19	Manured.....	} Jointing.....	{ 153.0 62.2	{ 3.23 1.26	{ 2.11 2.03	} 1918-49	{ 22.0 20.8	{ 32.2 25.2
Percentage increase over check.....		Check.....		146	156	4		6	28
Archer, Wyo.....	{ 71 19	Manured.....	} Headed.....	{ 253.0 310.0	{ 4.00 4.00	{ 1.58 1.29	} 1914-47	{ 7.4 10.2	{ (2) (2)
Percentage increase over check.....		Check.....		-18	0	22		-27	
Newell, S. Dak.....	{ 71 19	Manured.....	} Tillering.....	{ 35.4 20.9	{ 1.49 .76	{ 4.20 3.64	} 1909-49	{ 16.2 17.2	{ 13.0 13.5
Percentage increase over check.....		Check.....		69	96	15		-6	-4

North Platte, Nebr.-----	{ 268 MF-1	Manured..... Check.....	}Jointing.....	{ 448.5 202.0	13.54 4.36	3.02 2.16	} 1937-49	{ 28.2 30.9	19.7 12.2
Percentage increase over check.....				122	211	40		-9	61
North Platte, Nebr.-----	{ 43 3	Manured..... Check.....	}Jointing.....	{ 90.2 50.3	2.00 1.06	2.22 2.10	} 1937-49	{ 8.8 8.0	8.8 1.8
Percentage increase over check.....				79	89	6		10	389
Colby, Kans.-----	{ 564 565	Manured..... Check.....	}Early jointing.....	{ 108.5 98.5	3.80 3.04	3.50 3.09	} 1932-49	{ 7.7 5.9	(?) (?)
Percentage increase over check.....				10	25	13		31	
Hays, Kans.-----	{ 556 553	Manure (6 tons)..... Check.....	}Jointing.....	{ 32.5 27.5	1.24 .98	3.80 3.58	} 1914-49	{ 22.5 24.2	2.8 2.7
Percentage increase over check.....				18	26	6		-7	4
Hays, Kans.-----	{ 560 553	Manure (12 tons)..... Check.....	}Jointing.....	{ 41.0 27.5	1.69 .98	4.13 3.58	} 1914-49	{ 20.2 24.2	3.8 2.7
Percentage increase over check.....				49	72	15		-17	41
Woodward, Okla.-----	{ H-7/311-C H-5/309-C	Manured..... Check.....	}Prebooting.....	{ 763.5 373.9	11.91 5.68	1.56 1.52	} 1932-49	{ 24.1 23.1	25.8 24.2
Percentage increase over check.....				104	110	3		4	7

<sup>1</sup> Damaged by hail.

<sup>2</sup> Hulled out.

<sup>3</sup> Winter wheat. Stands were poor in 1949.

<sup>4</sup> Spring wheat. Severely injured by greenbugs.

majority of the locations, indicating a greater abundance of available nitrogen in the soil. This favorable effect in the earlier stages of growth was reflected in some instances in the yields of grain obtained in 1949. For example, at Mandan, Dickinson, Sheridan, and North Platte, marked increases were noted in growth early in the season from the use of manure; and these locations showed the greatest increase in grain yields. At Newell, however, there was a marked increase in early growth but a slight reduction in grain yield. At Woodward, there was also a marked increase in early growth due to manuring, but only a slight increase was obtained in yield. These results show that increased growth in the early stages of the wheat plant is not always indicative of higher grain yields, particularly in the Great Plains region where moisture is an important factor.

The longtime average yields show that in 7 of the 13 comparisons, the check plot outyielded the plots receiving manure. In 1949 there were only 2 such instances. Furthermore, the percentage increase in 1949 was greater in every instance than that for the longtime average. Because the 1949 data are for 1 year only, they should not be considered conclusive; but they do indicate that the response to manure should become greater with time, inasmuch as nonmanured land declines in fertility at a more rapid rate. The effects of barnyard manure on crop yields are discussed more fully in the next section.

### Effects of Soil-Nitrogen Changes on Crop Yields

Probably the first question to be raised in connection with changes in soil nitrogen is, "What effect have these changes had on crop yields?" That is, have the losses or gains in soil nitrogen over a period of years had any marked effect on crop yields? Jenny (24) referred to work done at Wooster, Ohio, which showed an almost linear relationship between the decline in soil nitrogen and corn yields under a continuous-cropping system. Smith and coworkers (42) reported on organic matter and yield trends with cropping on the Texas Blacklands, and stated that during a 20-year period of continuous cropping to corn, cotton, or oats, there was no obvious trend in yield with the passing of time. In one instance, however, they were able to detect a tendency toward lower corn yields with time when extremely poor yields caused by weather were eliminated.

Hill (22), reporting on wheat-yield trends in Canada, showed that where an alternate wheat and fallow system has been practiced for a 40-year period, there has been no important change in yield. He believes that this practice can be continued profitably for many years in western Canada if soil erosion and weeds are controlled.

To determine yield trends with the passing of time in the Great Plains, where variations in weather are extreme, seemed to be an almost impossible task. Rainfall is the main limiting factor—not only the amount that falls during the crop year, but also its distribution. However, as long as no trends in the weather develop with time, perhaps an estimate of yield trends can be made. Or, if trends in weather do develop, these can be eliminated to some extent by the use of multiple regression. Other factors which add to the difficulties of determining yield trends are insect pests, the occurrence of new strains of plant diseases, changes in varieties, and weeds.

To simplify the task of determining yield trends, the data from only 6 locations were analyzed<sup>8</sup> and their results are given (table 25).

Because of the possibility of a trend in precipitation with the passing of time, multiple regression was used. Thus, there were 2 independent variables—precipitation ( $X_1$ ) and years of cropping ( $X_2$ ). The dependent variable was yield ( $Y$ ).

The yields of corn grain, corn stover, and wheat grain under 4 different cropping systems were used in the computations. The 4 systems were continuous cropping, alternate crop and fallow, a 3-year rotation without manure, and a similar rotation with manure. The 3-year rotations consisted of corn, wheat, oats, at all locations except Hays, where it was kafir, fallow, wheat. Years with zero yields in which hail damage occurred were omitted.

From time to time, changes were made in varieties at some of the stations, and these no doubt influenced the results to a certain extent. However, it was felt that these changes were not of sufficient magnitude to be serious; fairly large differences would be required to be significant, because of the extreme variations in annual yields.

In these computations, the amount of precipitation assigned to each year of cropping was that amount which fell between harvest of one crop and harvest of the next. Thus, the amounts varied, not only with the crop but also with the cropping system. (See appendix table 47.) For example, in the instance of continuous wheat, the amount of precipitation for a given year would be that which fell between one wheat harvest and the next. In the instance of alternate wheat and fallow, it would be that which fell during a 2-year period. It was thought that these values were the best obtainable under the circumstances and would be better than those obtained by using annual or seasonal precipitation, although it was recognized that intensity of rainfall, distribution, runoff, and evaporation play important parts in determining the amount of water available for plant use.

The results obtained from the multiple-regression analysis (table 25) are based on the assumption that the regression was linear. This may or may not be correct for all locations. The regression was tested for curvilinearity at one location, but only slight evidence of this was found. The simple correlation coefficients ( $r$ ) show the relationship between any two of the variables. The correlation coefficients for precipitation and years of cropping ( $X_1$  and  $X_2$ ) show that there was very little relationship between these two variables at all locations, except for a few instances at Sheridan, Wyo., and Hays, Kans. In other words, there were no marked trends in precipitation with the passing of time, except as just explained.

The correlation coefficients for yield and precipitation ( $Y$  and  $X_1$ ) show the high dependency of yield on moisture in most instances. There was only one instance in which the relationship between yield of wheat and precipitation did not show significance, but there were several such instances with respect to row-crop yields and precipitation. The rela-

<sup>8</sup> The authors are indebted to D. D. Mason, former biometrician, and E. J. Koch, associate biometrician, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md., for their assistance in the statistical analyses.

TABLE 25.—Simple correlation coefficients (r) for comparing the relationship between any 2 of the variables—precipitation ( $X_1$ ), years of cropping ( $X_2$ ) and yield (Y); multiple-correlation coefficients (R); and the multiple-regression equation; at 6 locations in the Great Plains

MANDAN, N. DAK. (1915-45)

Crops and treatment	Number of years <sup>1</sup>	Simple correlation (r) <sup>2</sup>			Multiple correlation (R) <sup>2</sup>	Multiple-regression equation <sup>3</sup>
		$X_1$ and $X_2$	Y and $X_1$	Y and $X_2$		
Corn (grain):						
Continuous.....	29	0.257	0.142	-0.272	0.349	$Y=24.46+0.69 X_1-0.34 X_2$
Alternate fallow.....	29	.118	-.133	-.385*	.395	$Y=43.19-0.16 X_1-0.41 X_2^*$
Rotation without manure.....	29	.178	.366	-.072	.392	$Y=10.91+1.14 X_1^*-0.15 X_2$
Rotation with manure.....	29	.178	.469*	-.122	.513*	$Y=-6.54+2.26 X_1^{**}-0.33 X_2$
Corn (stover):						
Continuous.....	30	.203	-.033	-.615**	.622**	$Y=2,503.1+16.9 X_1-41.0 X_2^{**}$
Alternate fallow.....	30	.085	-.277	-.527**	.576**	$Y=3,855.8-33.2 X_1-47.2 X_2^{**}$
Rotation without manure.....	30	.231	.150	-.279	.356	$Y=1,608.2+29.5 X_1-16.6 X_2$
Rotation with manure.....	30	.231	.459*	.026	.467*	$Y=1,154.8+110.8 X_1^*-7.6 X_2$
Spring wheat (grain):						
Continuous.....	29	.178	.718**	.283	.735**	$Y=-17.41+1.94 X_1^{**}+0.15 X_2$
Alternate fallow.....	30	.052	.587**	.206	.613**	$Y=-14.37+1.07 X_1^{**}+0.21 X_2$
Rotation without manure.....	29	.116	.633**	-.022	.640**	$Y=-3.29+1.50 X_1^{**}-0.08 X_2$
Rotation with manure.....	27	.167	.486*	.331	.548*	$Y=-6.06+1.59 X_1^*+0.27 X_2$

DICKINSON, N. DAK. (1908-49)

Corn (grain):						
Continuous.....	31	-0.041	0.537**	-0.268	0.591**	$Y=5.59+1.58 X_1^{**}-0.24 X_2$
Alternate fallow.....	31	.047	-.061	-.273	.277	$Y=37.80-0.09 X_1-0.27 X_2$
Rotation without manure.....	27	-.006	.645**	-.109	.654**	$Y=-18.23+2.30 X_1^{**}-0.11 X_2$
Rotation with manure.....	27	-.006	.667**	-.013	.667**	$Y=-33.10+3.21 X_1^{**}-0.01 X_2$
Corn (stover):						
Continuous.....	37	.072	.427**	-.202	.486*	$Y=1,625.8+156.5 X_1^{**}-25.5 X_2$
Alternate fallow.....	37	.046	-.076	-.073	.103	$Y=4,640.8-19.4 X_1-10.1 X_2$
Rotation without manure.....	37	.028	.673**	-.190	.705**	$Y=-987.1+282.5 X_1^{**}-27.0 X_2$
Rotation with manure.....	37	.028	.766**	-.001	.766**	$Y=-3,307.3+465.2 X_1^{**}-4.2 X_2$
Spring wheat (grain):						
Continuous.....	36	.052	.688**	-.120	.705**	$Y=-12.07+1.72 X_1^{**}-0.10 X_2$
Alternate fallow.....	38	.058	.686**	-.082	.697**	$Y=-16.60+1.26 X_1^{**}-0.11 X_2$
Rotation without manure.....	38	.144	.694**	-.109	.725**	$Y=-9.09+1.93 X_1^{**}-0.15 X_2$
Rotation with manure.....	37	.139	.653**	+.065	.654**	$Y=-18.13+2.77 X_1^{**}-0.03 X_2$

## HAVRE, MONT. (1917-49)

Corn (grain):						
Continuous.....	21	-0.227	0.645**	-0.165	0.645**	$Y = -10.09 + 2.25 X_1^{**} - 0.02 X_2$
Alternate fallow.....	23	-1.157	.581**	-.058	.582*	$Y = -7.83 + 1.31 X_1^{**} + 0.04 X_2$
Rotation without manure.....	16	-.352	.681**	-.143	.689*	$Y = -21.11 + 2.70 X_1^{**} + 0.14 X_2$
Rotation with manure.....	16	-.352	.718**	-.272	.718**	$Y = -29.73 + 3.46 X_1^{**} - 0.04 X_2$
Corn (stover):						
Continuous.....	32	-.182	.479**	-.648**	.745**	$Y = 1,579.0 - 127.5 X_1^{**} - 58.8 X_2^{**}$
Alternate fallow.....	32	-.287	.047	-.431*	.438*	$Y = 4,167.4 - 25.2 X_1 - 59.6 X_2^{**}$
Rotation without manure.....	32	-.207	.708**	-.447*	.772**	$Y = -372.0 + 223.5 X_1^{**} - 33.6 X_2^{**}$
Rotation with manure.....	32	-.207	.710**	-.417*	.762**	$Y = -833.7 + 288.6 X_1^{**} - 38.5 X_2^{**}$
Spring wheat (grain):						
Continuous.....	31	-.146	.787**	-.130	.787**	$Y = -14.81 + 1.99 X_1^{**} - 0.01 X_2$
Alternate fallow.....	32	-.270	.737**	.025	.773**	$Y = -36.05 + 2.02 X_1^{**} + 0.25 X_2$
Rotation without manure.....	32	-.125	.764**	-.151	.766**	$Y = -13.01 + 2.43 X_1^{**} - 0.05 X_2$
Rotation with manure.....	32	-.125	.670**	-.250	.691**	$Y = -9.72 + 2.36 X_1^{**} - 0.17 X_2$

## SHERIDAN, WYO. (1918-49)

Corn (grain):						
Continuous.....	27	0.234	0.094	-0.698**	0.747**	$Y = 17.71 + 0.82 X_1 - 0.68 X_2^{**}$
Alternate fallow.....	29	.430*	.099	-.488**	.596**	$Y = 14.22 + 0.48 X_1^{**} - 0.49 X_2^{**}$
Rotation without manure.....	27	.276	.408*	-.504**	.760**	$Y = -3.78 + 1.78 X_1^{**} - 0.63 X_2^{**}$
Rotation with manure.....	27	.276	.460*	-.442*	.750**	$Y = -6.36 + 1.83 X_1^{**} - 0.56 X_2^{**}$
Corn (stover):						
Continuous.....	32	.312	.279	-.464**	.644**	$Y = 631.7 + 75.1 X_1^{**} - 41.0 X_2^{**}$
Alternate fallow.....	32	.434*	-.120	-.427*	.433*	$Y = 1,368.6 + 7.2 X_1 - 28.5 X_2^{**}$
Rotation without manure.....	32	.342	.542**	-.326	.768**	$Y = -86.8 + 116.0 X_1^{**} - 38.7 X_2^{**}$
Rotation with manure.....	32	.342	.657**	-.164	.776**	$Y = -409.9 + 152.1 X_1^{**} - 35.4 X_2^{**}$
Spring wheat (grain):						
Continuous.....	30	.383*	.575**	-.036	.638**	$Y = -6.18 + 1.42 X_1^{**} - 0.22 X_2$
Alternate fallow.....	32	.446*	.656**	.263	.657**	$Y = -13.97 + 1.22 X_1^{**} - 0.04 X_2$
Rotation without manure.....	29	.278	.594**	.086	.600**	$Y = -8.49 + 1.88 X_1 - 0.09 X_2$
Rotation with manure.....	30	.265	.725**	.247	.727**	$Y = -16.19 + 2.30 X_1^{**} + 0.07 X_2$

See footnotes at end of table.



TABLE 25.—Simple correlation coefficients ( $r$ ) for comparing the relationship between any 2 of the variables—precipitation ( $X_1$ ), years of cropping ( $X_2$ ) and yield ( $Y$ ); multiple-correlation coefficients ( $R$ ); and the multiple-regression equation; at 6 locations in the Great Plains—Con.

ARCHER, WYO. (1914-45)

Crops and treatment	Number of years <sup>1</sup>	Simple correlation ( $r$ ) <sup>2</sup>			Multiple correlation ( $R$ ) <sup>2</sup>	Multiple-regression equation <sup>3</sup>
		$X_1$ and $X_2$	$Y$ and $X_1$	$Y$ and $X_2$		
Corn, (grain):						
Continuous.....	27	.208	.178	-.309	.396	$Y=12.84+0.50 X_1-0.27 X_2$
Alternate fallow.....	28	.141	.203	-.090	.235	$Y=7.94+0.37 X_1-0.09 X_2$
Rotation without manure.....	26	.105	.350	-.266	.464	$Y=3.90+0.89 X_1-0.25 X_2$
Rotation with manure.....	26	.105	.460*	-.072	.476	$Y=-6.51+1.23 X_1^*-0.11 X_2$
Corn, (stover):						
Continuous.....	30	.117	.056	-.449*	.462*	$Y=1,736.0+28.8 X_1-43.2 X_2^*$
Alternate fallow.....	30	.076	.136	-.326	.364	$Y=1,105.0+29.7 X_1-27.7 X_2$
Rotation without manure.....	30	.000	.282	-.513**	.585**	$Y=960.9+77.8 X_1-48.6 X_2^*$
Rotation with manure.....	30	.000	.350	-.374*	.512*	$Y=412.5+97.8 X_1^*-35.9 X_2^*$
Spring wheat, (grain):						
Continuous.....	29	.081	.431*	-.154	.471*	$Y=-3.87+0.98 X_1^*-0.14 X_2$
Alternate fallow.....	30	.032	.400*	.041	.401	$Y=-5.89+0.65 X_1^*+0.02 X_2$
Rotation without manure.....	29	.163	.566**	-.121	.606**	$Y=-1.94+1.37 X_1^{**}-0.17 X_2$
Rotation with manure.....	29	.163	.553**	-.155	.606**	$Y=-2.61+1.48 X_1^{**}-0.21 X_2$

HAYS, KANS. (1914-48)

Kafr (grain):						
Continuous.....	24	.296	.623**	.062	.636**	$Y=-29.51+2.35 X_1^{**}-0.26 X_2$
Alternate fallow.....	25	.439*	.357	.042	.379	$Y=-26.13+1.45 X_1-0.34 X_2$
Rotation without manure.....	23	.375	.460*	.105	.466	$Y=-32.64+2.04 X_1^*-0.16 X_2$
Rotation with manure.....	24	.399	.437*	.194	.438	$Y=-37.97+2.08 X_1+0.06 X_2$
Kafr (stover):						
Continuous.....	35	.110	.537**	-.402*	.710**	$Y=+1,017.9+202.1 X_1^{**}-86.5 X_2^{**}$
Alternate fallow.....	35	.142	.537**	-.361*	.687**	$Y=-537.8+179.1 X_1^{**}-98.4 X_2^{**}$
Rotation without manure.....	35	.087	.682**	-.101	.701**	$Y=-3,354.8+283.6 X_1^{**}-37.6 X_2$
Rotation with manure.....	35	.087	.680**	.022	.681**	$Y=-3,949.1+294.8 X_1^{**}-9.2 X_2$
Winter wheat (grain):						
Continuous.....	29	.274	.400*	-.012	.419	$Y=-0.72+0.91 X_1^*-0.15 X_2$
Alternate fallow.....	34	.175	.163	-.094	.205	$Y=+13.16+0.32 X_1-0.16 X_2$
Rotation without manure.....	33	.168	.463**	.027	.466*	$Y=-8.23+0.90 X_1^{**}-0.07 X_2$
Rotation with manure.....	33	.168	.395*	-.102	.430*	$Y=-2.01+0.72 X_1^*-0.21 X_2$

<sup>1</sup> Number of years of data used in multiple regression. Years with zero yields, or when crops were damaged by hail, were omitted.<sup>2</sup> 1 asterisk (\*) indicates significant at 5-percent level; 2 asterisks (\*\*) indicate significant at 1-percent level.

tionship between yield on summer fallow and precipitation was lower in many instances, as would be expected.

The relationship between yield and years of cropping is shown by the  $r$  value for  $Y$  and  $X_2$ . These coefficients, however, are not independent of the effect of precipitation, although precipitation would influence the results only in instances in which it was related to years of cropping. As these correlations are not independent of the effects of precipitation, the effects of years of cropping on yield for a constant precipitation value are discussed fully in a later paragraph.

The multiple correlation coefficients ( $R$ ) show the combined relationship of both precipitation and years of cropping to yield. Although many of these tested highly significant, the largest coefficient was 0.787 for continuous wheat at Havre, Mont. The square of this coefficient would indicate that 62 percent of the variation in yield is the result of precipitation and years of cropping. Thus, even though many of the coefficients tested highly significant, precipitation and years of cropping did not account for a particularly large percentage of the variation in yield.

In the regression equation for calculating yield from precipitation and years of cropping, the coefficient of  $X_1$  indicates the yield change per inch of change in precipitation for a constant number of years of cropping. The negative values for alternate corn and fallow at some locations are difficult to explain. It was expected that corn on fallow would not be influenced as much by precipitation as corn on cropped land, but it was not expected that a negative relationship would be obtained. Also, the regression coefficients for precipitation were higher in the rotation receiving manure than in the rotation without manure, in every instance except two. This was to be expected, inasmuch as the greater fertility from manuring should result in greater increases in yield per inch of water.

The coefficient of  $X_2$  indicates the change in yield per year of cropping for a constant precipitation value. It will be noted that corn or kafir grain and stover yields declined in every instance except three. However, not all of these tested significant. When the crop was wheat, both increases and decreases were obtained, but none tested significant. From these results, it is apparent that corn or kafir yields were significantly reduced by cropping at some locations, whereas wheat yields were not. Many of the yield changes per year appeared high but were found to be nonsignificant. Apparently, the variation in yield was so great that extremely large yield changes were required to test significant.

(See appendix table 47 for actual average yields and calculated yields for the first and last years of the cropping periods shown.)

A clearer picture of the effect of years of cropping on yields is presented (table 26), together with the changes that occurred in soil nitrogen. The percentage change in soil nitrogen was computed as shown earlier (p. 16), and the percentage change in yield was calculated (see footnote 1 to table 26). The data are not comparable across stations, as yield change is a direct function of years of cropping.

It will be noted that the decline in yield was greater under continuous cropping than under alternate cropping and fallow in nearly every instance, and the difference was more striking for wheat than for row crops. These results are in agreement with those obtained by Greaves and

TABLE 26.—*Comparison of the percentage change in soil nitrogen with the percentage change in yield<sup>1</sup> of row crops<sup>2</sup> and wheat under 4 cropping systems at 6 locations*

ROW CROP, GRAIN									
Location	Period	Continuous		Alternate fallow		Rotation			
		Soil-nitrogen change	Yield change	Soil-nitrogen change	Yield change	Without manure		With manure	
						Soil-nitrogen change	Yield change	Soil-nitrogen change	Yield change
	Years	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Mandan, N. Dak.....	30	-35	-29	-40	-32	-34	-15	0	-32
Dickinson, N. Dak.....	40	-58	-31	-60	-31	-49	-20	-39	-2
Havre, Mont.....	31	-50	-4	-53	+5	-48	32	-26	-8
Sheridan, Wyo.....	30	-30	-67	-35	-50	-30	-73	-2	-69
Archer, Wyo.....	34	-43	-46	-43	-17	-37	-43	-19	-24
Hays, Kans.....	30	-29	-36	-40	-27	-35	-17	-22	7
Average.....	33	-41	-36	-45	-25	-39	-23	-18	-21

ROW CROP, STOVER									
Mandan, N. Dak.....	30	-35	-45	-40	-51	-34	-24	0	-8
Dickinson, N. Dak.....	40	-58	-25	-60	-10	-49	-27	-39	-3
Havre, Mont.....	31	-50	-61	-53	-53	-48	-42	-26	-42
Sheridan, Wyo.....	30	-30	-68	-35	-50	-30	-63	-2	-50
Archer, Wyo.....	34	-43	-69	-43	-48	-37	-72	-19	-57
Hays, Kans.....	30	-29	-50	-40	-41	-35	-22	-22	-6
Average.....	33	-41	-53	-45	-42	-39	-42	-18	-28

WHEAT, GRAIN									
Mandan, N. Dak.....	30	-19	37	-26	34	-34	-14	0	49
Dickinson, N. Dak.....	40	-44	-26	-50	-19	-49	-33	-39	-6
Havre, Mont.....	31	-44	-4	-42	66	-48	-13	-26	-36
Sheridan, Wyo.....	30	-21	-40	-27	-5	-30	-13	-2	10
Archer, Wyo.....	34	-32	-47	-33	5	-37	-43	-19	-50
Hays, Kans.....	30	-10	-24	-7	-18	-35	-9	-22	-26
Average.....	33	-28	-17	-31	11	-39	-21	-18	-10

<sup>1</sup> The percentage yield change was computed by dividing the calculated yield change for the period by the calculated yield in the first year and multiplying by 100. The yield change was determined by multiplying the regression coefficient for  $X_1$  in the multiple-regression equation, by the number of years in the period. The yield in the first year was determined from the multiple-regression equation, by substituting the average precipitation for the period for  $X_1$ , and by substituting 1 for  $X_2$ .

<sup>2</sup> The row crop was corn at all locations except Hays, in which it was kafir.

Bracken (19) in Utah and by Hill (22) in Canada. The authors of this bulletin agree with Hill's explanation (p. 15): "The fact that yields of wheat on fallow have been maintained, whereas those of wheat following wheat have fallen off, may be due partially to the improved availability of nutrients after the fallow season. As the native fertility is gradually reduced, this factor may become more important."

Growing the crops in rotation without manure reduced the decline in yield at some locations more than did either continuous or alternate fallow, but increased it at others. The average values show that the decline in yield for crops in rotation was similar to that of alternate fallow in the instance of row crops but greater in the instance of wheat.

In comparing the nonmanured and the manured rotations, the results

were found to be variable. The most consistent results were those for row-crop stover, for which the decline in yield was equal to or less than that of the nonmanured rotation at every location. Why manuring should cause a greater decrease in yield with the passing of time than nonmanuring at some locations is not known, for the nitrogen content of the soil had not been increased above its original value at any of the locations, and therefore the tendency for burning should not have increased. Hill (22, p. 15) stated: "Yields [of wheat at Brandon, Manitoba], have been somewhat better in the manured rotation as compared to the unmanured, but not enough to warrant the cost of applying the manure." This statement is no doubt true for some of the locations reported on in this publication. With continued cropping of the soil, however, the benefit derived from manuring should increase.

In comparing the percentage change in soil nitrogen with the percentage change in yield, it will be noted that there is no apparent relationship between the two. At one location a low percentage change in nitrogen may result in a large change in yield, whereas at another location the reverse may be true. Climate and the adaptability of the crop may be factors influencing the results. For example, the soil at one location may have had greater fertility than was necessary to produce maximum yields under the climatic conditions at that location. Thus, fairly large declines in fertility could occur without seriously influencing yields. On the other hand, at another location the fertility may have originally been barely adequate to produce good yields, in which instance even small declines in fertility may have reduced yields considerably.

Since periodic soil-nitrogen determinations had been made at Sheridan, Wyo., and at Hays, Kans., it was possible to compare periodic changes in nitrogen with changes in crops yields. To make them comparable, both the nitrogen and the yields were placed on a relative basis. In other words, the nitrogen content of the soil at each sampling date was expressed as a percentage of the nitrogen content on the first sampling date. The yield for each subsequent date was calculated from the multiple-regression equation, the average precipitation for the period being used as  $X_1$ , and the calculated yield for each date being expressed as a percentage of the yield on the first date. The results are presented (table 27). Soil-nitrogen data were not available for all sampling dates for some of the cropping treatments.

At Sheridan, the relative values for corn and stover yields were lower than for soil nitrogen in every instance, while those for wheat yields were higher in every instance except for that which was continuously cropped. This would indicate that corn yields have declined at a greater rate than soil nitrogen, while the reverse is true for wheat. The corn and wheat grain yields are presented graphically (figs. 7 and 8, respectively), together with the relative soil-nitrogen values, to bring out these points more clearly.

In the manured rotation, the extreme contrast in yield trends of corn, as compared with those of wheat, is difficult to explain. Both the corn and the wheat were grown in the same rotation on the same soil; yet corn yields dropped sharply and wheat yields increased slightly with little change in soil nitrogen. Apparently, there is some factor that influences corn yields but does not affect wheat yields.

TABLE 27.—*Comparison of relative content of soil nitrogen with relative yield of row crops and wheat under 4 cropping treatments during different years at Sheridan, Wyo., and Hays, Kans.*

## SHERIDAN, WYO.

Crops and year	Continuous		Alternate		Rotation			
	Relative soil nitrogen	Relative yield	Relative soil nitrogen	Relative yield	Without manure		With manure	
					Relative soil nitrogen	Relative yield	Relative soil nitrogen	Relative yield
Corn, grain:	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1917.....	100	100	100	100	100	100	100	100
1927.....	-----	78	86	83	-----	76	96	77
1937.....	-----	55	77	66	-----	51	95	54
1947.....	70	33	65	50	70	27	98	31
Corn, stover:								
1917.....	100	100	100	100	100	100	100	100
1927.....	-----	77	86	83	-----	79	96	83
1937.....	-----	55	77	66	-----	58	95	67
1947.....	70	32	65	50	70	37	98	50
Wheat, grain:								
1917.....	100	100	100	100	100	100	100	100
1927.....	-----	87	91	98	-----	96	96	103
1937.....	-----	73	80	97	-----	91	95	107
1947.....	79	60	73	95	70	87	98	110

## HAYS, KANS.

Kafir, grain:								
1916.....	100	100	100	100	100	100	100	100
1927.....	-----	87	81	90	-----	94	-----	102
1938.....	74	73	68	80	68	87	81	105
1946.....	71	64	60	73	65	83	79	107
Kafir, stover:								
1916.....	100	100	100	100	100	100	100	100
1927.....	-----	82	81	85	-----	92	-----	98
1938.....	74	63	68	70	68	84	81	96
1946.....	71	50	60	59	65	78	79	94
Wheat, grain:								
1916.....	100	100	100	100	100	100	100	100
1927.....	96	92	98	93	-----	97	-----	90
1938.....	88	83	90	87	68	94	81	81
1946.....	90	76	93	82	65	91	79	74

At Hays, the relative values for yield of kafir grain and stover were higher than for soil nitrogen in every instance except for stover under continuous cropping. Relative values for kafir-grain yields under continuous cropping and stover yields under alternate fallow were approximately equal to those for soil nitrogen. For wheat, the relative yield values were less than those of soil nitrogen under continuous and alternate cropping, greater in a rotation without manure, and about equal in a rotation with manure. These results were almost the reverse of those obtained at Sheridan.

From these results, it would be difficult to make an overall statement as to the effects on crop yields of losses or gains in soil nitrogen. Apparently, the effect was considerable at some locations and only slight at others, but row crops in general were influenced more than wheat.

Further evidence that nitrogen may not be limiting wheat yields at many of the locations is shown by the results of fertilizer tests conducted

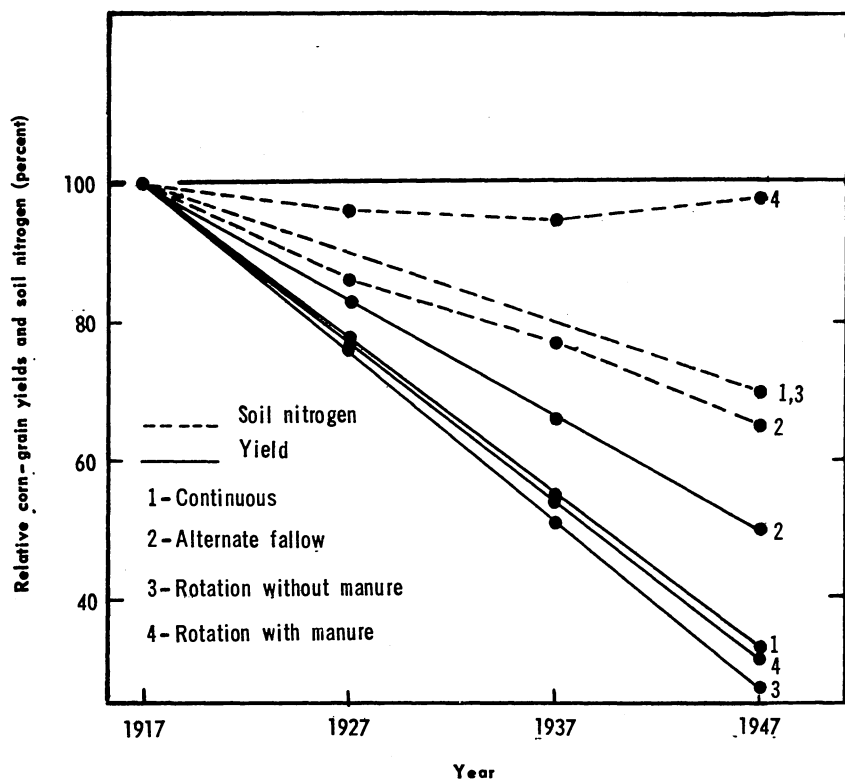


FIGURE 7.—Comparison of relative corn-grain yields and relative soil-nitrogen values on different dates from 4 cropping treatments at Sheridan, Wyo.

at 13 locations in the Great Plains, 1950-52. The average yields obtained from these tests are presented (table 28). It will be noted that Mandan and Hays were the only locations that showed much response to nitrogen. In individual years, however, response was observed at some of the other locations. It is interesting to note that at Garden City, Kans., and Woodward, Okla., no response was obtained, even though the nitrogen content of the soil is low at those locations. The discussion on nitrification (p. 33) brought out the fact that the Garden City soils had a relatively high rate of nitrification in relation to the total soil-nitrogen level; this may have provided the necessary soluble nitrate-nitrogen for crop production.

Moisture is no doubt limiting the response to nitrogen fertilizer in many instances. More moisture is generally available on fallowed than on cropped land, but at the same time there is usually more available nitrogen present under fallow. Thus, nitrogen fertilizers should not be expected greatly to influence yields under this treatment.

More emphasis should be placed on conserving moisture so that crops

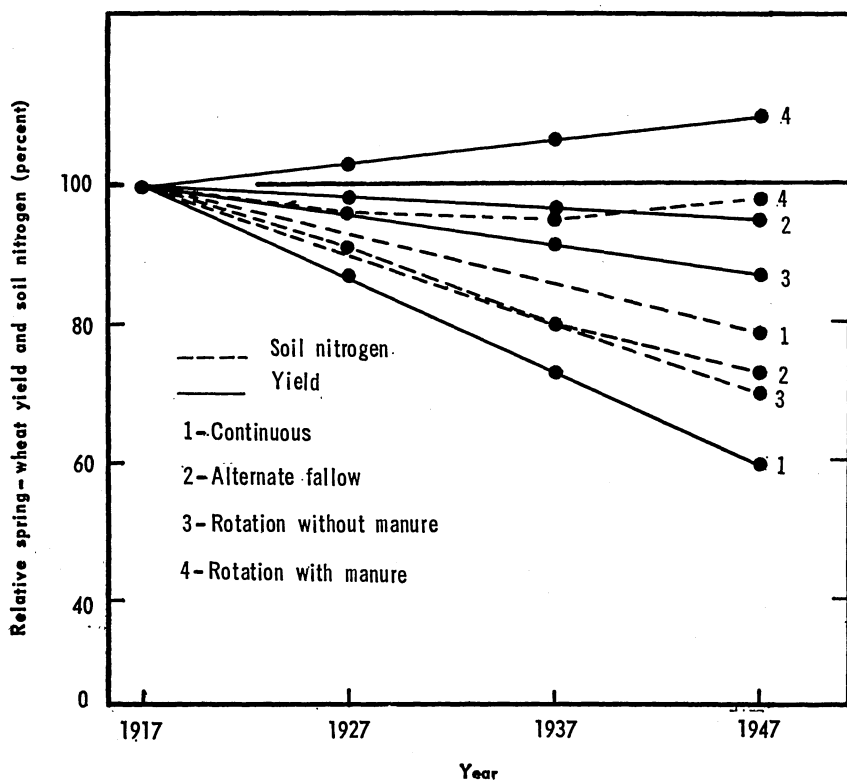


FIGURE 8.—Comparison of relative wheat-grain yields and relative soil-nitrogen values on different dates from 4 cropping treatments at Sheridan, Wyo.

TABLE 28.—Total nitrogen content of soil, and average yield of wheat with and without fertilizer, at 13 locations in the Great Plains, 1950-52

Location	Years	Previous crop	Soil nitrogen		Grain yield	
			0 to 6 inches	6 to 12 inches	Check	Nitrogen applied <sup>1</sup>
	Number		Percent	Percent	Bushels	Bushels
Mandan, N. Dak.	2	Wheat	0.118	0.112	9.5	13.1
Dickinson, N. Dak.	2	Crested wheat and wheat.	.168	.124	13.8	13.2
Moccasin, Mont.	2	Wheat	.218	.191	16.8	17.2
Huntley, Mont.	3	Fallow	.092	.072	17.3	15.7
Newell, S. Dak.	3	Wheat	.120	.098	11.6	11.5
Sheridan, Wyo.	3	Wheat	.136	.123	16.4	17.8
Archer, Wyo.	2	Fallow	.087	.087	21.5	21.4
North Platte, Nebr.	2	do	.089	.085	26.0	26.7
Akron, Colo.	2	do			22.9	21.8
Do	1	Wheat			6.9	6.3
Colby, Kans.	1	Fallow	.090	.096	16.3	15.1
Hays, Kans.	3	Wheat	.116	.095	22.6	29.6
Garden City, Kans.	1	Fallow	.064	.068	18.3	18.2
Woodward, Okla.	3	Wheat	.049	.053	22.3	21.3

<sup>1</sup> From 20 to 40 pounds of nitrogen applied per acre.

can be grown every year. With increased moisture storage, greater responses to nitrogen fertilizers could be expected; and it might be possible to eliminate summer fallow, which is a source of much wind and water erosion difficulty and is responsible for great depletion of soil nitrogen and carbon.

### Summary

A study was made of the effect of cropping on the carbon and nitrogen content of the soil at 14 locations in the Great Plains. The period of cropping ranged from 30 to 43 years, and the loss of nitrogen varied from 24 to 60 percent. The average of all locations was 39 percent loss of nitrogen over a 36-year period. Organic carbon losses were similar to nitrogen losses except that they were slightly greater.

Samples were collected periodically at 4 locations. The results at 3 of these locations in Kansas showed a sharp decline in nitrogen the first 10 to 20 years, with a tendency to level off in the later years. At Sheridan, Wyo., the decline was almost linear, with little leveling off.

An attempt was made to determine whether one type of small grain influenced nitrogen or carbon losses more than another. As nearly as could be determined, there was little difference in their effect on these losses.

Land which had been continuously cropped to small grains, or which had been alternately cropped to small grains and fallow, lost much less nitrogen than that which had been planted to row crops. Alternate small-grain and fallow land lost more nitrogen than that continuously cropped, at every location except one; with row crops, however, the loss was greater under alternate row crop and fallow than under continuous row crop, at only 7 out of 13 locations. The average loss from the surface soil under these cropping treatments at 11 locations was 24 percent for continuous small grains, 29 percent for alternate small grains and fallow, and 43 percent for both continuous row crop and alternate row crop and fallow. Losses from the subsurface soils were considerably less than from surface soils.

Applications of barnyard manure reduced the loss of nitrogen at all locations, compared with similar rotations without manure. At 1 location an increase in nitrogen was noted. The average loss at 12 locations was 37 percent from a rotation without manure and 25 percent from a rotation receiving manure.

Neither rye nor legumes used as green manure were effective in reducing the loss of nitrogen.

The effect of grass in a rotation on the loss of soil nitrogen was studied at 3 locations, and the effect of alfalfa at 4 locations. Both grass and alfalfa reduced the losses in each instance except alfalfa at 1 location. Neither grass nor alfalfa maintained the nitrogen at its original level.

The relationship between total nitrogen in the soil and nitrate production during a 6-week incubation period was determined on a total of 214 samples from 13 locations. There was a relationship between total nitrogen and nitrate production at all but 2 locations. The correlation coefficient for all samples was 0.562, which was highly significant. In addition to the 6-week incubation period, 1 high- and 1 low-nitrogen soil from each location was incubated for 12, 18, and 24 weeks. The high-



nitrogen soils not only produced more nitrate during the first 6-week period but were able to maintain a higher rate of nitrification during longer periods of incubation.

The effect of cropping on the total nitrogen content of the soil was compared with the effect of cropping on nitrate-nitrogen production. The results varied considerably between locations; but the average loss of nitrogen was 39 percent, and the average loss in nitrate-nitrogen producing ability of the soil was 35 percent.

The type of crop growing on the land immediately prior to time of sampling had little effect upon nitrate production. However, there was evidence in the majority of the samples that those samples from summer fallow were able to produce less nitrate during incubation than those from cropped land.

The effect of barnyard manure on the early growth and nitrogen content of wheat plants was determined at 11 locations. Expressed as a percentage of the checks, the effect of manure on plant weight ranged from a decrease of 18 percent at Archer, Wyo., to an increase of 146 percent at Sheridan, Wyo. The effect of manure on the weight of nitrogen in the plants ranged from 0 at Archer, Wyo., to an increase of 211 percent in winter wheat at North Platte, Nebr. The effect of manure on the percentage nitrogen in the plants ranged from a 10-percent decrease at Mandan, N. Dak., to an increase of 40 percent at North Platte, Nebr. Increased early growth from the use of manure resulted in increased grain yields in some instances but not in all.

An attempt was made to determine the effect of years of cropping or of the decline in soil nitrogen on crop yields. As nearly as could be determined from data at 6 locations, row-crop yields declined significantly in some instances while wheat yields did not. Although none of the changes in wheat yields tested significant, there was evidence that continuous cropping reduced yields more than alternate cropping and fallow, even though soil nitrogen losses were greater under alternate cropping and fallow. In some instances, yields from a rotation receiving manure declined more than from a nonmanured rotation, but in general, the decline was not as great, and in a few instances yields increased. When the percentage changes in soil nitrogen were compared with the percentage changes in yield, there was apparently little relationship between the two. In some instances yield changes were greater than the nitrogen changes, while in others, the reverse was true.

Fertilizer trials conducted during a 3-year period at 13 locations showed that wheat responded to nitrogen at only 2 of these locations. There were individual years, however, in which responses were obtained at a few of the other locations. This indicated the probability that in many instances moisture is still the main limiting factor.

## Literature Cited

- (1) ALBRECHT, W. A.  
1937. THE NITRATE NITROGEN IN THE SOIL AS INFLUENCED BY THE CROP AND THE SOIL TREATMENTS. Mo. Agr. Expt. Sta. Bul. 250, 27 pp., illus.
- (2) ALLISON, F. E., and STERLING, L. D.  
1949. NITRATE FORMATION FROM SOIL ORGANIC MATTER IN RELATION TO TOTAL NITROGEN AND CROPPING PRACTICES. Soil Sci. 67: 239-252, illus.
- (3) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.  
1950. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . Ed. 7, 932 pp., illus.
- (4) ATKINSON, H. J., and WRIGHT, L. E.  
1948. COMPARATIVE EFFECT OF KEEPING SOIL UNDER CONTINUOUS CULTIVATION AND KEEPING IT IN CONTINUOUS GRASS. Sci. Agr. 28: 30-33.
- (5) BRACKEN, A. F., and LARSON, L. H.  
1947. INCREASES IN NITROGEN FROM GROWING ALFALFA ON DRY LAND. Soil Sci. 64: 37-45.
- (6) BRACE, B. L., THOMPSON, M. J., and CALDWELL, A. C.  
1952. LONG-TIME EFFECT OF APPLYING BARNYARD MANURE AT VARIED RATES ON CROP YIELD AND SOME CHEMICAL CONSTITUENTS OF THE SOIL. Agron. Jour. 44: 17-20.
- (7) BROADBENT, F. E.  
1951. DENITRIFICATION IN SOME CALIFORNIA SOILS. Soil Sci. 72: 129-137, illus.
- (8) CARPENTER, R. W., HAAS, H. J., and MILES, E. F.  
1952. NITROGEN UPTAKE BY WHEAT IN RELATION TO NITROGEN CONTENT OF SOIL. Agron. Jour. 44: 420-423, illus.
- (9) CHANG, C. W.  
1950. EFFECT OF LONG-TIME CROPPING ON SOIL PROPERTIES IN NORTHEASTERN NEW MEXICO. Soil Sci. 69: 359-368.
- (10) CHAPMAN, H. D., and LIEBIG, G. F., Jr.  
1947. NITROGEN GAINS AND LOSSES IN THE GROWTH OF LEGUME AND NON-LEGUME COVER CROPS AT VARIOUS LEVELS OF NITROGEN FERTILIZATION. (Abstract) Soil Sci. Soc. Amer. Proc. (1946) 11: 388.
- (11) DETURK, E. E.  
1942. THE PROBLEM OF PHOSPHATE FERTILIZERS. Ill. Agr. Expt. Sta. Bul. 484, pp. [541]-[584], illus.
- (12) DULEY, F. L.  
1924. CONTROLLING SURFACE EROSION OF FARM LANDS. Mo. Agr. Expt. Sta. Bul. 211, 23 pp., illus.
- (13) ——— and MILLER, M. F.  
1923. EROSION AND SURFACE RUNOFF UNDER DIFFERENT SOIL CONDITIONS. Mo. Agr. Expt. Sta. Res. Bul. 63, 50 pp., illus.
- (14) ——— and RUSSEL, J. C.  
1942. USING CROP RESIDUES FOR SOIL DEFENSE. U. S. Dept. Agr. Misc. Pub. 494, 16 pp., illus.
- (15) FRAPS, G. S.  
1920. NITRIFICATION IN TEXAS SOILS. Tex. Agr. Expt. Sta. Bul. 259, 37 pp., illus.
- (16) ——— and STERGES, A. J.  
1932. CAUSES OF LOW NITRIFICATION CAPACITY OF CERTAIN SOILS. Soil Sci. 34: 353-363, illus.
- (17) GAINES, P. L.  
1936. TOTAL NITROGEN AS A FACTOR INFLUENCING NITRATE ACCUMULATION IN SOILS. Soil Sci. 42: 157-163.
- (18) ——— SEWELL, M. C., and LATSHAW, W. L.  
1929. THE NITROGEN BALANCE IN CULTIVATED SEMI-ARID WESTERN KANSAS SOILS. Amer. Soc. Agron. Jour. 21: 1130-1153.
- (19) GREAVES, J. E., and BRACKEN, A. F.  
1946. EFFECT OF CROPPING ON THE NITROGEN, PHOSPHORUS, AND ORGANIC CARBON CONTENT OF A DRY-FARM SOIL AND ON THE YIELD OF WHEAT. Soil Sci. 62: 355-364, illus.
- (20) ——— and JONES, L. W.  
1950. INFLUENCE OF LEGUMES ON SOIL NITROGEN. Soil Sci. 69: 71-76.

- (21) HIDE, J. C., and METZGER, W. H.  
1939. THE EFFECT OF CULTIVATION AND EROSION ON THE NITROGEN AND CARBON OF SOME KANSAS SOILS. *Amer. Soc. Agron. Jour.* 31: 625-632, illus.
- (22) HILL, K. W.  
1954. THESE SOILS HAVE GROWN WHEAT FOR FIFTY YEARS. *What's New in Crops and Soils* 6 (7): 14-15, illus.
- (23) HORNER, G. M., McCALL, A. G., and BELL, F. G.  
1944. INVESTIGATIONS IN EROSION CONTROL AND RECLAMATION OF ERODED LAND AT THE PALOUSE CONSERVATION EXPERIMENT STATION, PULLMAN, WASH., 1931-42. *U. S. Dept. Agr. Tech. Bul.* 860, 83 pp., illus.
- (24) JENNY, H.  
1941. FACTORS OF SOIL FORMATION. A SYSTEM OF QUANTITATIVE PEDOLOGY. 281 pp., illus. New York and London.
- (25) JONES, J. S., and YATES, W. W.  
1924. THE PROBLEM OF SOIL ORGANIC MATTER AND NITROGEN IN DRY-LAND AGRICULTURE. *Amer. Soc. Agron. Jour.* 16: 721-731.
- (26) JONES, R. J.  
1942. NITROGEN LOSSES FROM ALABAMA SOILS IN LYSIMETERS AS INFLUENCED BY VARIOUS SYSTEMS OF GREEN MANURE CROP MANAGEMENT. *Amer. Soc. Agron. Jour.* 34: 574-585, illus.
- (27) LANGHAM, W. H.  
1937. FERTILITY LOSSES FROM HIGH PLAINS SOILS DUE TO WIND EROSION. *Okla. Panhandle Agr. Expt. Sta. Bul.* 63, 15 pp., illus.
- (28) LYON, T. L.  
1929. ORGANIC MATTER PROBLEMS IN HUMID SOILS. *Amer. Soc. Agron. Jour.* 21: 951-957.
- (29) ——— and WILSON, B. D.  
1928. SOME RELATIONS OF GREEN MANURES TO THE NITROGEN OF A SOIL. *N. Y. (Cornell) Agr. Expt. Sta. Mem.* 115, 29 pp., illus.
- (30) McHENRY, J. R., ALEXANDER, L. T., and ZOOK, L. L.  
1947. CARBON AND NITROGEN CONTENTS OF A CHERNOZEM SOIL AS AFFECTED BY AGE OF PERENNIAL GRASS SODS. *Soil Sci. Soc. Amer. Proc.* (1946) 11: 407-412, illus.
- (31) MCKAY, H. C., and MOSS, W. A.  
1944. STUBBLE MULCH FARMING IN SOUTHERN IDAHO. *Idaho Agr. Expt. Sta. Bul.* 256, 20 pp., illus.
- (32) MUSGRAVE, G. W., and NORTON, R. A.  
1937. SOIL AND WATER CONSERVATION INVESTIGATIONS AT THE SOIL CONSERVATION EXPERIMENT STATION, MISSOURI VALLEY LOESS REGION, CLARINDA, IOWA. *U. S. Dept. Agr. Tech. Bul.* 558, 182 pp., illus.
- (33) MYERS, H. E., HALLSTED, A. L., KUSKA, J. B., and HAAS, H. J.  
1943. NITROGEN AND CARBON CHANGES IN SOILS UNDER LOW RAINFALL AS INFLUENCED BY CROPPING SYSTEMS AND SOIL TREATMENT. *Kans. Agr. Expt. Sta. Tech. Bul.* 56, 52 pp., illus.
- (34) NEWTON, J. D., WYATT, F. A., and BROWN, A. L.  
1945. EFFECTS OF CULTIVATION AND CROPPING ON THE CHEMICAL COMPOSITION OF SOME WESTERN CANADA PRAIRIE PROVINCE SOILS. *Sci. Agr.* 25: 718-737.
- (35) PEECH, M., ALEXANDER, L. T., DEAN, L. A., and REED, J. F.  
1947. METHODS OF SOIL ANALYSIS FOR SOIL-FERTILITY INVESTIGATIONS. *U. S. Dept. Agr. Cir.* 757, 25 pp.
- (36) ROGERS, H. T.  
[1942.] PLANT NUTRIENT LOSSES BY EROSION FROM A CORN, WHEAT, CLOVER ROTATION ON DUNMORE SILT LOAM. *Soil Sci. Soc. Amer. Proc.* (1941) 6: 263-271, illus.
- (37) RUSSEL, J. C.  
1929. ORGANIC MATTER PROBLEMS UNDER DRY-FARMING CONDITIONS. *Amer. Soc. Agron. Jour.* 21: 960-969.
- (38) RUSSELL, Sir E. J.  
1950. SOIL CONDITIONS & PLANT GROWTH. Ed. 8, 635 pp., illus. London, New York, etc.

- (39) SALTER, R. M., and GREEN, T. C.  
1933. FACTORS AFFECTING THE ACCUMULATION AND LOSS OF NITROGEN AND ORGANIC CARBON IN CROPPED SOILS. *Amer. Soc. Agron. Jour.* 25: 622-630, illus.
- (40) SEWELL, M. C., and GAINES, P. L.  
1932. ORGANIC MATTER CHANGES IN DRY-FARMING REGIONS. *Amer. Soc. Agron. Jour.* 24: 275-283.
- (41) SMITH, H. W. and VANDECAVEYE, S. C.  
1946. PRODUCTIVITY AND ORGANIC MATTER LEVELS OF PALOUSE SILT LOAM AS AFFECTED BY ORGANIC RESIDUES AND NITROGEN FERTILIZERS. *Soil Sci.* 62: 283-291.
- (42) SMITH, R. M., THOMPSON, D. O., COLLIER, J. W., and HERVEY, R. J.  
1954. SOIL ORGANIC MATTER, CROP YIELDS, AND LAND USE IN THE TEXAS BLACKLAND. *Soil Sci.* 77: 377-388, illus.
- (43) STEWART, R.  
1910. THE NITROGEN AND HUMUS PROBLEM IN DRY-LAND FARMING. *Utah Agr. Expt. Sta. Bul.* 109, 16 pp.
- (44) ——— and HIRST, C. T.  
1914. NITROGEN AND ORGANIC MATTER IN DRY-FARM SOILS. *Amer. Soc. Agron. Jour.* 6: 49-56.
- (45) THATCHER, R. W.  
1912. THE NITROGEN AND HUMUS PROBLEM IN DRY FARMING. *Wash. Agr. Expt. Sta. Bul.* 105, 16 pp.
- (46) TIDMORE, J. W., and VOLK, N. J.  
1945. THE EFFECT OF PLOWING UNDER AND THE TIME OF PLOWING UNDER LEGUMES ON THE CONSERVATION OF NITROGEN. *Amer. Soc. Agron. Jour.* 37: 1005-1010.
- (47) VOLKERDING, C. C., and STOA, T. E.  
1947. WHAT IS HAPPENING TO OUR SOIL FERTILITY. *N. Dak. Agr. Expt. Sta. Bimonthly Bul.* 10 (1): [3]-12.
- (48) WAKSMAN, S. A.  
1923. MICROBIOLOGICAL ANALYSIS OF SOIL AS AN INDEX OF SOIL FERTILITY: VI, NITRIFICATION. *Soil Sci.* 16: 55-66, illus.
- (49) WEAVER, J. E., and NOLL, W. C.  
1935. COMPARISON OF RUNOFF AND EROSION IN PRAIRIE, PASTURE, AND CULTIVATED LAND. *Univ. Nebr. Conserv. and Survey Div., Bul.* 11, 37 pp., illus.
- (50) WOODRUFF, C. M.  
1950. ESTIMATING THE NITROGEN DELIVERY OF SOIL FROM THE ORGANIC MATTER DETERMINATION AS REFLECTED BY SANBORN FIELD. *Soil Sci. Soc. Amer. Proc.* (1949) 14: 208-212.

## APPENDIX

TABLE 29.—*Nitrogen and carbon content and carbon/nitrogen ratio of*

CONTINUOUS SPRING

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—			
					0 to 6 inches		6 to 12 inches	
					1914	1943	1914	1943
M. C.-----	A-B	Spring wheat—plowed-----	1914	2	<i>Pct.</i> 0.178	<i>Pct.</i> 0.142	<i>Pct.</i> 0.138	<i>Pct.</i> 0.142
M. C.-----	A-B	Oats—plowed-----	1914	2	.142	.114	.108	.108
M. C.-----	A-B	Barley—plowed-----	1914	2	.212	.179	.158	.162
Average..	-----	-----	-----	-----	.177	.145	.135	.137

ALTERNATE SPRING

M. C.-----	C-D	Spring wheat, fallow-----	1914	2	0.190	0.140	0.147	0.140
M. C.-----	C-D	Oats, fallow-----	1914	2	.155	.112	.118	.106
M. C.-----	C-D	Barley, fallow-----	1914	2	.211	.152	.154	.141
Average..	-----	-----	-----	-----	.185	.135	.140	.129

CONTINUOUS

M. C.-----	A-B	Corn—plowed-----	1914	2	0.170	0.110	0.130	0.112
------------	-----	------------------	------	---	-------	-------	-------	-------

ALTERNATE ROW

M. C.-----	C-D	Corn, fallow-----	1914	2	0.166	0.100	0.120	0.098
------------	-----	-------------------	------	---	-------	-------	-------	-------

ALTERNATE ROW CROP

40-----	A-B	Corn, oats-----	1914	2	0.142	0.100	0.108	0.092
49-----	A-B	Corn, spring wheat-----	1914	2	.144	.102	.108	.098
Average..	-----	-----	-----	-----	.143	.101	.108	.095

ROW CROP, SMALL GRAIN,

2-----	A-C	Corn, spring wheat, oats-----	1914	9	0.159	0.105	0.118	0.102
3-----	A-C	do-----	1914	3	.141	.102	.102	.087
13-----	A-C	do-----	1914	3	.161	.115	.119	.110
Average..	-----	-----	-----	-----	.154	.107	.113	.100

ROW CROP (MANURED),

68-----	A-C	Corn (manured), spring wheat, oats.	1914	3	0.144	0.143	0.106	0.116
---------	-----	-------------------------------------	------	---	-------	-------	-------	-------

See footnotes at end of table.

# TABLES

*the soil, under various rotations at Mandan, N. Dak., 1914<sup>1</sup> and 1943*

## SMALL GRAIN

Nitrogen at—		Carbon at—						Ratio of carbon to nitrogen at—					
12 to 24 inches		0 to 6 inches		6 to 12 inches		12 to 24 inches		0 to 6 inches		6 to 12 inches		12 to 24 inches	
1914	1943	1914	1943	1914	1943	1914	1943	1914	1943	1914	1943	1914	1943
<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>						
0.096	0.096	2.34	1.82	1.72	1.76	1.18	1.17	13.1	12.8	12.5	12.4	12.3	12.2
.076	.078	1.88	1.42	1.36	1.33	.91	.92	13.2	12.5	12.6	12.3	12.0	11.8
.104	.098	2.76	2.26	1.98	2.07	1.28	1.18	13.0	12.6	12.5	12.8	12.3	12.0
.092	.091	2.33	1.83	1.69	1.72	1.12	1.09	13.1	12.6	12.5	12.5	12.2	12.0

## SMALL GRAIN AND FALLOW

0.100	0.089	2.48	1.77	1.84	1.74	1.22	1.02	13.1	12.6	12.5	12.4	12.2	11.5
.078	.072	2.04	1.39	1.48	1.32	.95	.82	13.2	12.4	12.5	12.5	12.2	11.4
.098	.084	2.75	1.94	1.93	1.78	1.20	.97	13.0	12.8	12.5	12.6	12.2	11.5
.092	.082	2.42	1.70	1.75	1.61	1.12	.94	13.1	12.6	12.5	12.5	12.2	11.5

## ROW CROP

0.083	0.074	2.24	1.38	1.64	1.34	1.00	0.87	13.2	12.5	12.6	12.0	12.0	11.8
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## CROP AND FALLOW

0.076	0.066	2.19	1.23	1.49	1.20	0.91	0.76	13.2	12.3	12.4	12.2	12.0	11.5
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## AND SMALL GRAIN

0.072	0.066	1.87	1.19	1.35	1.12	0.86	0.78	13.2	11.9	12.5	12.2	11.9	11.8
.074	.074	1.90	1.26	1.36	1.24	.89	.87	13.2	12.4	12.6	12.7	12.0	11.8
.073	.070	1.88	1.22	1.36	1.18	.88	.82	13.2	12.2	12.6	12.4	12.0	11.8

## SMALL GRAIN

0.082	0.075	2.09	1.31	1.47	1.26	0.99	0.89	13.1	12.5	12.5	12.4	12.1	11.9
.069	.065	1.85	1.23	1.28	1.08	.82	.76	13.1	12.1	12.5	12.4	11.9	11.7
.090	.091	2.12	1.45	1.50	1.39	1.09	1.07	13.2	12.6	12.6	12.6	12.1	11.8
.080	.077	2.02	1.33	1.42	1.24	.97	.91	13.1	12.4	12.5	12.5	12.0	11.8

## SMALL GRAIN, SMALL GRAIN

0.076	0.081	1.89	1.76	1.33	1.45	0.92	0.97	13.1	12.3	12.5	12.5	12.1	12.0
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

See footnotes at end of table.

TABLE 29.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil,*  
FALLOW, SMALL GRAIN,

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—			
					0 to 6 inches		6 to 12 inches	
					1914	1943	1914	1943
5.....	A-C	Fallow, spring wheat, oats....	1914	3	<i>Pct.</i> 0.136	<i>Pct.</i> 0.096	<i>Pct.</i> 0.103	<i>Pct.</i> 0.094
8.....	A-C	Fallow, oats, spring wheat....	1914	3	.176	.126	.134	.121
Average..	-----	-----	-----	-----	.156	.111	.118	.108
ROW CROP, SMALL GRAIN								
19.....	A-D	Corn, spring wheat, fallow, oats.	1914	4	0.157	0.109	0.120	0.104
ROW CROP, SMALL GRAIN, RYE (GREEN								
14.....	A-D	Corn, spring wheat, winter rye (green-manured), oats.	1914	4	0.161	0.110	0.119	0.103
ROW CROP, SMALL GRAIN,								
31.....	A-D	Corn, spring wheat, sweet-clover (green-manured), oats.	1914	4	0.145	0.102	0.107	0.098
ROW CROP, SMALL GRAIN, FALLOW								
71.....	A-D	Corn, spring wheat, fallow (manured), oats.	1914	4	0.134	0.124	0.099	0.103
ROW CROP, SMALL GRAIN, SMALL								
41 <sup>2</sup> .....	A-F	Corn, spring wheat, oats, 3 plots grass.	1914	6	0.149	0.112	0.106	0.100
ROW CROP, SMALL GRAIN, SMALL GRAIN,								
42 <sup>2</sup> .....	A-F	Corn, spring wheat, oats, 3 plots alfalfa.	1914	6	0.164	0.134	0.119	0.122
VIRGIN								
(None)....	-----	Native grasses.....	-----	15	-----	0.156	-----	0.111

<sup>1</sup> Nitrogen and carbon values in 1914 were calculated as described in text.<sup>2</sup> The symbol "M. C." means "Methods of cropping."

under various rotations at Mandan, N. Dak., 1914<sup>1</sup> and 1943—Continued

## SMALL GRAIN

Nitrogen at—		Carbon at—						Ratio of carbon to nitrogen at—					
12 to 24 inches		0 to 6 inches		6 to 12 inches		12 to 24 inches		0 to 6 inches		6 to 12 inches		12 to 24 inches	
1914	1943	1914	1943	1914	1943	1914	1943	1914	1943	1914	1943	1914	1943
<i>Pct.</i> 0.075 .088	<i>Pct.</i> 0.075 .083	<i>Pct.</i> 1.80 2.31	<i>Pct.</i> 1.19 1.54	<i>Pct.</i> 1.29 1.68	<i>Pct.</i> 1.19 1.48	<i>Pct.</i> 0.90 1.07	<i>Pct.</i> 0.92 .95	13.2 13.1	12.4 12.2	12.5 12.5	12.7 12.2	12.0 12.2	12.3 11.4
.082	.079	2.06	1.36	1.48	1.34	.98	.94	13.2	12.3	12.5	12.4	12.1	11.8

## FALLOW, SMALL GRAIN

0.086	0.082	2.06	1.37	1.50	1.34	1.04	1.01	13.1	12.6	12.5	12.9	12.1	12.3
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## MANURE), SMALL GRAIN

0.090	0.082	2.12	1.36	1.50	1.29	1.10	0.97	13.2	12.4	12.6	12.5	12.2	11.8
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## LEGUME (GREEN MANURE), SMALL GRAIN

0.080	0.078	1.90	1.28	1.35	1.21	0.98	0.94	13.1	12.5	12.6	12.3	12.3	12.1
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## (MANURED), SMALL GRAIN

0.074	0.079	1.77	1.57	1.24	1.30	0.89	0.94	13.2	12.7	12.5	12.6	12.0	11.9
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## GRAIN, GRASS, GRASS, GRASS

0.077	0.077	1.96	1.40	1.33	1.23	0.93	0.96	13.2	12.5	12.5	12.3	12.1	12.5
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## ALFALFA, ALFALFA, ALFALFA

0.089	0.093	2.16	1.65	1.49	1.54	1.08	1.11	13.2	12.3	12.5	12.6	12.1	11.9
-------	-------	------	------	------	------	------	------	------	------	------	------	------	------

## SOD

-----	0.081	-----	2.05	-----	1.39	-----	0.98	-----	13.1	-----	12.5	-----	12.1
-------	-------	-------	------	-------	------	-------	------	-------	------	-------	------	-------	------

<sup>1</sup> Changed to deferred type rotation in 1937.



TABLE 30.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Dickinson, N. Dak., 1947*

## CONTINUOUS SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. C.-----	A-B-----	Spring wheat—plowed-----	1907	2	Percent 0.162	Percent 0.116	Percent 1.80	-----	11.0	-----
M. C.-----	A-B-----	Oats—plowed-----	1907	2	.154	.114	-----	-----	-----	-----
M. C.-----	A-B-----	Barley—plowed-----	1907	2	.173	.132	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.163	.121	-----	-----	-----	-----

## ALTERNATE SMALL GRAIN AND FALLOW

M. C.-----	C-D-----	Spring wheat, fallow-----	1907	2	0.148	0.102	1.62	-----	10.9	-----
M. C.-----	C-D-----	Oats, fallow-----	1907	2	.139	.095	-----	-----	-----	-----
M. C.-----	C-D-----	Barley, fallow-----	1907	2	.152	.100	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.147	.099	-----	-----	-----	-----

## CONTINUOUS ROW CROP

M. C.-----	A-B-----	Corn—plowed-----	1907	2	0.120	0.083	1.33	0.92	11.0	11.2
------------	----------	------------------	------	---	-------	-------	------	------	------	------

## ALTERNATE ROW CROP AND FALLOW

M. C.-----	C-D-----	Corn, fallow-----	1907	2	0.118	0.090	1.28	1.04	10.8	11.6
------------	----------	-------------------	------	---	-------	-------	------	------	------	------

## ROW CROP, SMALL GRAIN, SMALL GRAIN

7-----	A-C-----	Corn, oats, barley-----	1907	3	0.148	0.115	-----	-----	-----	-----
9-----	A-C-----	Corn, oats, spring wheat-----	1907	3	.150	.111	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.149	.113	-----	-----	-----	-----

## ROW CROP (MANURED), SMALL GRAIN, SMALL GRAIN

62.....	A-C.....	Corn (manured), spring wheat, oats.....	1907	3	0.180	0.146	2.08	1.66	11.5	11.3
---------	----------	-----------------------------------------	------	---	-------	-------	------	------	------	------

## FALLOW, SMALL GRAIN, SMALL GRAIN

5.....	A-C.....	Fallow, spring wheat, oats.....	1907	3	0.142	0.100	-----	-----	-----	-----
8.....	A-C.....	Fallow, oats, spring wheat.....	1907	3	.147	.103	-----	-----	-----	-----
Average.....					.145	.102	-----	-----	-----	-----

## PEAS (GREEN MANURE), SMALL GRAIN, SMALL GRAIN

61.....	A-C.....	Peas (green manure), spring wheat, oats.....	1907	3	0.147	0.105	-----	-----	-----	-----
---------	----------	----------------------------------------------	------	---	-------	-------	-------	-------	-------	-------

## WINTER RYE (GREEN MANURE), SMALL GRAIN, SMALL GRAIN

63.....	A-C.....	Winter rye (green manure), spring wheat oats.....	1907	3	0.153	0.111	-----	-----	-----	-----
---------	----------	---------------------------------------------------	------	---	-------	-------	-------	-------	-------	-------

## ROW CROP, SMALL GRAIN, WINTER RYE (GREEN MANURE), SMALL GRAIN

15.....	A-D.....	Corn, oats, winter rye (green manure), spring wheat.....	1907	4	0.149	0.111	-----	-----	-----	-----
---------	----------	----------------------------------------------------------	------	---	-------	-------	-------	-------	-------	-------

## ROW CROP, SMALL GRAIN, LEGUME (GREEN MANURE), SMALL GRAIN

16.....	A-D.....	Corn, spring wheat, peas (green manure), oats.....	1907	4	0.151	0.118	-----	-----	-----	-----
17.....	A-D.....	Corn, oats, peas (green manure), spring wheat.....	1907	4	.132	.092	-----	-----	-----	-----
31.....	A-D.....	Corn, spring wheat, sweetclover (green manure), oats.....	1907	4	.168	.111	-----	-----	-----	-----
32.....	A-D.....	Corn, oats, sweetclover (green manure), spring wheat.....	1907	4	.146	.105	-----	-----	-----	-----
Average.....					.149	.106	-----	-----	-----	-----

## ROW CROP, SMALL GRAIN, SMALL GRAIN, ALFALFA, ALFALFA, ALFALFA

42.....	A-F.....	Corn, oats, spring wheat, alfalfa, alfalfa, alfalfa.....	1907	6	0.163	0.112	-----	-----	-----	-----
---------	----------	----------------------------------------------------------	------	---	-------	-------	-------	-------	-------	-------

## VIRGIN SOD

(None).....		Native grass.....	-----	9	0.293	0.162	3.64	1.87	12.4	11.5
-------------	--	-------------------	-------	---	-------	-------	------	------	------	------

<sup>1</sup> The symbol "M. C." means "Methods of cropping."

TABLE 31.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil, under various rotations at Havre, Mont., 1947*

## CONTINUOUS SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. C.-----	A-B.-----	Winter wheat—plowed.....	1916	2	0.110	0.108	1.05	0.99	9.5	9.2
M. C.-----	A-B.-----	Spring wheat—plowed.....	1916	2	.088	.087	.87	.84	10.0	9.6
M. C.-----	A-B.-----	Oats—plowed.....	1916	2	.102	.096	.94	.90	9.2	9.3
M. C. <sup>2</sup> -----	A-B.-----	Spring rye—plowed.....	1927	2	.092	.088	.89	.83	9.7	9.3
Average-----	-----	-----	-----	-----	.098	.095	.94	.89	9.6	9.4

## ALTERNATE SMALL GRAIN AND FALLOW

M. C.-----	C-D.-----	Winter wheat, fallow.....	1916	2	0.098	0.104	0.88	0.94	8.9	9.0
M. C.-----	C-D.-----	Spring wheat, fallow.....	1916	2	.088	.095	.82	.90	9.4	9.4
M. C.-----	C-D.-----	Oats, fallow.....	1916	2	.092	.090	.82	.79	8.9	8.8
M. C. <sup>2</sup> -----	C-D.-----	Spring rye, fallow.....	1927	2	.087	.075	.78	.68	9.0	9.0
Average-----	-----	-----	-----	-----	.091	.091	.83	.82	9.0	9.0

## CONTINUOUS ROW CROP

M. C.-----	A-B.-----	Corn—plowed.....	1916	2	0.076	0.082	0.67	0.72	8.8	8.9
------------	-----------	------------------	------	---	-------	-------	------	------	-----	-----

## ALTERNATE ROW CROP AND FALLOW

M. C.-----	C-D.-----	Corn, fallow.....	1916	2	0.071	0.074	0.62	0.65	8.8	8.8
------------	-----------	-------------------	------	---	-------	-------	------	------	-----	-----

## ROW CROP, SMALL GRAIN, SMALL GRAIN

2.-----	A-C.-----	Corn, spring wheat, oats.....	1916	3	0.078	0.081	0.74	0.72	9.5	8.9
9.-----	A-C.-----	Corn, oats, spring wheat.....	1916	3	.084	.086	.82	.80	9.7	9.3
7.-----	A-C.-----	Corn, oats, barley.....	1916	3	.097	.090	.92	.82	9.5	9.1
Average-----	-----	-----	-----	-----	.086	.086	.82	.78	9.6	9.1

## ROW CROP, SMALL GRAIN, SMALL GRAIN (MANURED)

68.....	A-C.....	Corn (manured), oats, spring wheat.....	1916	3	0.112	0.096	1.08	0.89	9.7	9.2
69.....	A-C.....	Corn, oats, spring wheat (manured).....	1916	3	.102	.095	.97	.86	9.5	9.1
70.....	A-C.....	Corn, oats (manured), spring wheat.....	1916	3	.093	.076	.94	.72	10.1	9.4
Average.....					.102	.089	1.00	.82	9.8	9.2

## FALLOW, SMALL GRAIN, SMALL GRAIN

5.....	A-C.....	Fallow, spring wheat, oats.....	1916	3	0.097	0.097	0.90	0.87	9.3	9.0
8.....	A-C.....	Fallow, oats, spring wheat.....	1916	3	.092	.086	.85	.79	9.3	9.2
Average.....					.095	.092	.88	.83	9.3	9.1

## FALLOW, SMALL GRAIN, WINTER RYE

99 <sup>1</sup> .....	A-C.....	Fallow, spring wheat, winter rye.....	1937	3	0.098	0.102	0.89	0.88	9.0	8.7
-----------------------	----------	---------------------------------------	------	---	-------	-------	------	------	-----	-----

## FALLOW, SMALL GRAIN, WINTER RYE (GREEN MANURE)

98 <sup>2</sup> .....	A-C.....	Fallow, spring wheat, winter rye (green manure).....	1937	3	0.097	0.102	0.86	0.87	8.9	8.5
-----------------------	----------	------------------------------------------------------	------	---	-------	-------	------	------	-----	-----

## ROW CROP, SMALL GRAIN, FALLOW (MANURED), SMALL GRAIN

71.....	A-D.....	Corn, spring wheat, fallow (manured), oats.....	1916	4	0.106	0.093	1.00	0.86	9.4	9.2
72.....	A-D.....	Corn, oats, fallow (manured), spring wheat.....	1916	4	.121	.110	1.16	.97	9.6	8.9
Average.....					.114	.101	1.08	.92	9.5	9.1

## SMALL GRAIN, FALLOW, FALLOW, FALLOW

570.....	A-D.....	Spring wheat, fallow, fallow, fallow.....	1916	4	0.087	0.091	0.74	0.78	8.5	8.6
----------	----------	-------------------------------------------	------	---	-------	-------	------	------	-----	-----

## VIRGIN SOD

None.....		Native grasses.....		9	0.151	0.108	1.75	0.99	11.6	9.2
-----------	--	---------------------	--	---	-------	-------	------	------	------	-----

<sup>1</sup> The symbol "M. C." means "Methods of cropping."<sup>2</sup> From 1916 to 1926, inclusive, the area occupied by the M. C. rye plots was in M. C. flax plots.<sup>3</sup> From 1916 to 1936, inclusive, the area occupied by rotation 98 was in rotation 54, plots A, B, and C. That occupied by rotation 99 was formerly in rotation 54, plot D, and rotation 16, plots A and B. Both rotations 54 and 16 were 4-plot rotations containing peas plowed under for green manure.

TABLE 32.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Moccasin, Mont., 1947*

## CONTINUOUS SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—	Carbon at—	Ratio of carbon to nitrogen at—
					0 to 6 inches	0 to 6 inches	0 to 6 inches
					Percent	Percent	
M. C.....	A-B.....	Winter wheat—plowed.....	1908	2	0.200	2.21	11.0
M. C.....	A-B.....	Spring wheat—plowed.....	1908	2	.212	.....	.....
M. C.....	A-B.....	Oats—plowed.....	1908	2	.223	.....	.....
M. C.....	A-B.....	Barley—plowed.....	1908	2	.229	.....	.....
M. C. <sup>2</sup> .....	A-B.....	Spring rye—plowed.....	1933	2	.232	.....	.....
Average.....	.....	.....	.....	.....	.219	.....	.....

## ALTERNATE SMALL GRAIN AND FALLOW

M. C.....	C-D.....	Winter wheat, fallow.....	1908	2	0.208	2.17	10.4
M. C.....	C-D.....	Spring, wheat, fallow.....	1908	2	.196	.....	.....
M. C.....	C-D.....	Oats, fallow.....	1908	2	.190	.....	.....
M. C.....	C-D.....	Barley, fallow.....	1908	2	.192	.....	.....
M. C. <sup>2</sup> .....	C-D.....	Spring rye, fallow.....	1933	2	.190	.....	.....
Average.....	.....	.....	.....	.....	.195	.....	.....

## ROW CROP, SMALL GRAIN, SMALL GRAIN

1.....	A-C.....	Corn, spring wheat, oats.....	1908	3	0.193	.....	.....
2.....	A-C.....	do.....	1908	3	.205	.....	.....
9.....	A-C.....	Corn, oats, spring wheat.....	1908	3	.209	.....	.....
7.....	A-C.....	Corn, oats, barley.....	1908	3	.206	.....	.....
Average.....	.....	.....	.....	.....	.203	.....	.....

## ROW CROP (MANURED), SMALL GRAIN, SMALL GRAIN

67-----	A-C-----	Corn (manured), oats, spring wheat-----	1912	3	0.240	-----	-----
68-----	A-C-----	Corn (manured), spring wheat, oats-----	1912	3	.234	-----	-----
Average-----	-----	-----	-----	-----	.237	-----	-----

## ROW CROP, SMALL GRAIN, SWEETCLOVER (GREEN MANURE), SMALL GRAIN

31 <sup>1</sup> -----	A-D-----	Corn, spring wheat, sweetclover (green manure), oats-----	1937	4	0.206	-----	-----
32 <sup>1</sup> -----	A-D-----	Corn, oats, sweetclover (green manure), spring wheat-----	1937	4	.200	0.215	10.8
Average-----	-----	-----	-----	-----	.203	-----	-----

## VIRGIN SOD

None-----	-----	Native grass-----	-----	9	0.300	3.24	10.8
-----------	-------	-------------------	-------	---	-------	------	------

<sup>1</sup> The symbol "M. C." means "Methods of cropping."<sup>2</sup> From 1908 to 1932, inclusive, these plots were in M. C. flax.<sup>3</sup> From 1908 to 1936, inclusive, the area occupied by rotations 31 and 32 was in rotations 16 and 17 respectively, which contained peas instead of sweetclover.

TABLE 33.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Huntley, Mont., 1947*

## CONTINUOUS SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. C.-----	A-B-----	Winter wheat—plowed-----	1912	2	<i>Percent</i> 0.096	<i>Percent</i> 0.091	<i>Percent</i> 0.92	-----	9.7	-----
M. C.-----	A-B-----	Spring wheat—plowed-----	1912	2	.086	.084	-----	-----	-----	-----
M. C.-----	A-B-----	Oats—plowed-----	1912	2	.081	.084	-----	-----	-----	-----
M. C.-----	A-B-----	Barley—plowed-----	1914	2	.081	.062	-----	-----	-----	-----
M. C.-----	A-B-----	Flax—plowed-----	1912	2	.092	.095	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.087	.084	-----	-----	-----	-----

## ALTERNATE SMALL GRAIN AND FALLOW

M. C.-----	C-D-----	Winter wheat, fallow-----	1912	2	0.105	0.092	-----	0.89	-----	9.7
M. C.-----	C-D-----	Spring wheat, fallow-----	1912	2	.074	.076	-----	-----	-----	-----
M. C.-----	C-D-----	Oats, fallow-----	1912	2	.072	.065	-----	-----	-----	-----
M. C.-----	C-D-----	Barley, fallow-----	1914	2	.071	.048	-----	-----	-----	-----
M. C.-----	C-D-----	Flax, fallow-----	1912	2	.068	.072	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.078	.070	-----	-----	-----	-----

## ALTERNATE SMALL GRAIN AND FALLOW (MANURED)

38-----	A-B-----	Winter wheat, fallow-----	1914	2	0.122	0.080	1.20	0.76	9.8	9.5
39-----	A-B-----	Spring wheat, fallow-----	1914	2	.110	.065	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.116	.072	-----	-----	-----	-----

## CONTINUOUS ROW CROP

M. C.-----	A-B-----	Corn—plowed-----	1912	2	0.070	0.068	0.64	0.63	9.2	9.2
------------	----------	------------------	------	---	-------	-------	------	------	-----	-----

## ALTERNATE ROW CROP AND FALLOW

M. C.-----	C-D-----	Corn, fallow-----	1912	2	0.066	0.060	-----	-----	-----	-----
ROW CROP, SMALL GRAIN, RYE (GREEN MANURE), SMALL GRAIN										
51-----	A-D-----	Corn, barley, rye (green manure), winter wheat-----	1912	4	0.090	0.096	-----	-----	-----	-----
53-----	A-D-----	Corn, winter wheat, rye (green manure), barley-----	1912	4	.092	.088	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.91	.091	-----	-----	-----	-----
ROW CROP, SMALL GRAIN, PEAS (GREEN MANURE), SMALL GRAIN										
92-----	A-D-----	Corn, barley, peas (green manure), winter wheat-----	1912	4	0.093	0.090	-----	-----	-----	-----
54-----	A-D-----	Corn, winter wheat, peas (green manure), barley-----	1912	4	.099	.091	-----	-----	-----	-----
Average-----	-----	-----	-----	-----	.096	.090	-----	-----	-----	-----
SMALL GRAIN, FALLOW, FALLOW, FALLOW										
570-----	A-D-----	Spring wheat, fallow, fallow, fallow-----	1914	4	0.061	0.042	-----	-----	-----	-----

<sup>1</sup> The symbol "M. C." means "Methods of cropping."



TABLE 34.—*Nitrogen and carbon content and carbon/nitrogen ratio of soil from various rotations at Sheridan, Wyo., 1917 and 1947*

CONTINUOUS PEAS—PLOWED UNDER															
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Number of plots	Nitrogen at—				Carbon at—				Ratio of carbon to nitrogen at—			
				0 to 6½ inches		6½ to 20 inches		0 to 6½ inches		6½ to 20 inches		0 to 6½ inches		6½ to 20 inches	
				1917	1947	1917	1947	1917	1947	1917	1947	1917	1947	1917	1947
Continuous		Peas—plowed under	1	Percent 0.185	Percent 0.134	Percent 0.159	Percent 0.129	Percent 1.99	Percent 1.30	Percent 1.62	Percent 1.32	10.8	9.7	10.2	10.2
CONTINUOUS FALLOW															
Continuous		Fallow	1	0.166	0.095	0.103	0.079	1.86	0.94	1.18	0.84	11.2	9.9	11.5	10.6
CONTINUOUS SMALL GRAIN—PLOWED OR LISTED															
M. C. <sup>2</sup>	A-B	Spring wheat—plowed	2	0.140	0.111	0.103	0.102	1.50	1.09		0.97	10.7	9.8		9.5
M. C.	E-F	Spring wheat—E subsoiled, F listed.	2	.132	.109	.103	.096	1.34	1.01	0.98	.90	10.2	9.3	9.5	9.4
M. C. <sup>2</sup>	A-B	Oats—plowed	2	.140	.112	.096	.100	1.47	1.10		.97	10.5	9.8		9.7
M. C.	E-F	Oats—E subsoiled, F listed	2	.145	.113	.109	.101	1.45	1.03	1.04	1.01	10.0	9.1	9.5	10.0
M. C. <sup>2</sup>	A-B	Barley—plowed	2	.148	.116	.101	.104	1.62	1.08		.98	10.9	9.3		9.4
M. C.	E-F	Barley—E subsoiled, F listed	2	.162	.124	.116	.106	1.74	1.18	1.19	1.10	10.7	9.5	10.3	10.4
M. C.	A-B	Winter wheat—plowed	2	.153	.112	.108	.098	1.48	1.05	1.02	.92	9.7	9.4	9.4	9.4
M. C. <sup>3</sup>	E-F	Winter wheat—E subsoiled, F listed.	2	.142	.112	.102	.097	1.37	1.07	.99	.94	9.6	9.6	9.7	9.7
Average				.145	.114	.105	.101	1.50	1.08		.97	10.3	9.5		9.6
CONTINUOUS SMALL GRAINS—ALTERNATE PLOWED AND DISKED															
258	A-B	Oats and winter wheat	2	0.167	0.146	0.140	0.135	1.86	1.60	1.46	1.42	11.1	11.0	10.4	10.5
572	A-B	Winter wheat	2	.154	.128	.114	.106	1.63	1.31	1.10	1.04	10.6	10.2	9.6	9.8
577	A-B	Oats	2	.172	.156	.147	.145	1.79	1.58	1.48	1.44	10.4	10.1	10.1	9.9
Average				.164	.143	.134	.128	1.76	1.50	1.35	1.30	10.7	10.5	10.1	10.2

## CONTINUOUS SMALL GRAIN PLOWED 1 YEAR, DISKED 2 YEARS

573-----	A-C-----	Winter wheat-----	3	0.150	0.127	0.117	0.109	1.51	1.28	1.17	1.11	10.1	10.1	10.0	10.2
578-----	A-C-----	Oats-----	3	.159	.133	.120	.115	1.69	1.29	1.22	1.11	10.6	9.7	10.2	9.7
Average-----				.155	.130	.118	.112	1.60	1.28	1.20	1.11	10.3	9.8	10.2	9.9

## CONTINUOUS SMALL GRAIN-DISKED

571-----	A-----	Winter wheat-----	1	0.170	0.156	0.127	0.128	1.87	1.77	1.28	1.25	11.0	11.3	10.1	9.8
576-----	A-----	Oats-----	1	.186	.160	.142	.132	2.04	1.71	1.44	1.30	11.0	10.7	10.1	9.8
Average-----				.178	.158	.134	.130	1.96	1.74	1.36	1.28	11.0	11.0	10.1	9.8

## ALTERNATE SPRING SMALL GRAIN AND FALLOW

M. F. <sup>4</sup> -----	H-I-----	Spring wheat—fall-plowed, re- plowed in spring.	2	0.162	0.096	0.106	0.090	1.62	1.00	0.98	0.92	10.0	10.4	9.2	10.2
M. F. <sup>4</sup> -----	J-K-----	Spring wheat—fall-plowed	2	.148	.098	.092	.088	1.39	.98	.83	1.02	9.4	10.0	9.0	11.6
M. F. <sup>4</sup> -----	L-M-----	Spring wheat—plowed in May	2	.161	.097	.115	.086	1.54	1.02	1.08	.91	9.6	10.5	9.4	10.6
M. F. <sup>4</sup> -----	N-O-----	Spring wheat—plowed in June	2	.158	.106	.122	.093	1.45	1.12	1.16	1.00	9.2	10.6	9.5	10.8
M. C. <sup>3</sup> -----	C-D-----	Spring wheat—spring-plowed	2	.140	.102	.097	.088	1.46	.93	-----	.85	10.4	9.1	-----	9.7
M. C. <sup>3</sup> -----	C-D-----	Oats—spring-plowed	2	.142	.106	.103	.089	1.48	.98	-----	.82	10.4	9.2	-----	9.2
M. C. <sup>3</sup> -----	C-D-----	Barley—spring-plowed	2	.156	.113	.116	.097	1.67	1.06	-----	.98	10.7	9.4	-----	10.1
Average-----				.152	.102	.107	.090	1.52	1.01	-----	.93	10.0	9.9	-----	10.3

## ALTERNATE WINTER WHEAT AND FALLOW

M. C-----	C-D-----	Winter wheat and fallow-----	2	0.140	0.119	0.104	0.100	1.49	1.08	1.43	0.93	10.6	9.1	13.8	9.3
-----------	----------	------------------------------	---	-------	-------	-------	-------	------	------	------	------	------	-----	------	-----

## CONTINUOUS ROW CROP

M. C. <sup>3</sup> -----	A-B-----	Corn—plowed-----	2	0.144	0.098	0.100	0.092	1.49	0.91	-----	0.85	10.3	9.3	-----	9.2
M. C-----	E-F-----	Corn—E subsoiled, F listed	2	.145	.091	.092	.081	1.47	.84	0.87	.76	10.1	9.2	9.5	9.4
Average-----				.144	.094	.096	.086	1.48	.87	-----	.80	10.3	9.3	-----	9.3

See footnotes at end of table.

TABLE 34.—Nitrogen and carbon content and carbon/nitrogen ratio of soil from various rotations at Sheridan, Wyo., 1917 and 1947—Con.

## ALTERNATE ROW CROP AND FALLOW

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Number of plots	Nitrogen at—				Carbon at—				Ratio of carbon to nitrogen at—			
				0 to 6½ inches		6½ to 20 inches		0 to 6½ inches		6½ to 20 inches		0 to 6½ inches		6½ to 20 inches	
				1917	1947	1917	1947	1917	1947	1917	1947	1917	1947	1917	1947
M. C. <sup>2</sup>	C-D	Corn, fallow	2	Percent 0.140	Percent 0.091	Percent 0.097	Percent 0.084	Percent 1.46	Percent 0.82	Percent -----	Percent 0.77	10.4	9.0	-----	9.2

## ALTERNATE ROW CROP AND FLAX

243	A-B	Corn, flax	2	0.156	0.112	0.118	0.106	1.64	1.14	1.28	1.14	10.5	10.2	10.8	10.8
244	A-B	do	2	.141	.100	.107	.096	1.41	.98	1.06	.98	10.0	9.8	9.9	10.2
245	A-B	do	2	.145	.111	.114	.104	1.46	1.06	1.13	1.02	10.1	9.5	9.9	9.8
Average				.148	.108	.113	.102	1.50	1.06	1.15	1.05	10.1	9.8	10.2	10.3

## ALTERNATE ROW CROP (MANURED) AND FLAX

246	A-B	Corn, flax	2	0.143	0.202	0.106	0.105	1.46	2.15	1.08	1.10	10.2	10.6	10.2	10.5
-----	-----	------------	---	-------	-------	-------	-------	------	------	------	------	------	------	------	------

## ALTERNATE SMALL GRAIN AND FLAX

247	A-B	Spring wheat, flax	2	0.167	0.134	0.114	0.109	1.83	1.36	1.19	1.18	11.0	10.1	10.4	10.8
248	A-B	Oats, flax	2	.164	.127	.120	.108	1.72	1.33	1.26	1.18	10.5	10.5	10.5	10.9
Average				.165	.130	.117	.109	1.78	1.34	1.22	1.18	10.8	10.3	10.4	10.8

## ROW CROP, SMALL GRAIN, SMALL GRAIN

Checks	1-3	Corn, spring wheat, oats	3	0.134	0.102	0.101	0.094	1.35	0.95	1.00	0.88	10.1	9.3	9.9	9.4
Do	4-6	do	3	.153	.107	.116	.097	1.56	1.09	1.20	1.01	10.2	10.2	10.3	10.4
Do	7-9	do	3	.161	.115	.122	.107	1.70	1.13	1.27	1.17	10.6	9.8	10.4	10.9
Do	10-12	do	3	.147	.109	.112	.102	1.45	1.05	1.12	1.01	9.9	9.6	10.0	9.9
Do	13-15	do	3	.174	.124	.121	.107	1.80	1.21	1.21	1.06	10.3	9.8	10.0	9.9

Do	16-18	do	3	.168	.118	.122	.107	1.68	1.18	1.25	1.10	10.0	10.0	10.2	10.3
Do	19-21	do	3	.163	.126	.129	.124	1.69	1.32	1.30	1.23	10.4	10.5	10.1	9.9
Do	22-24	do	3	.183	.136	.147	.130	1.90	1.39	1.46	1.33	10.4	10.2	9.9	10.2
Do	25-27	do	3	.166	.122	.105	.102	1.77	1.19	1.03	.99	10.7	9.8	9.8	9.7
1	A-C	do	3	.172	.133	.109	.111	1.97	1.31	1.23	1.18	11.5	9.8	11.3	10.6
2	A-C	do	3	.186	.131	.125	.112	1.93	1.36	1.30	1.20	10.4	10.4	10.4	10.7
3	A-C	do	3	.175	.127	.127	.115	1.91	1.29	1.44	1.34	10.9	10.2	11.3	11.7
4	A-C	do	3	.158	.113	.113	.100	1.65	1.10	1.17	1.00	10.4	9.7	10.4	10.0
13	A-C	do	3	.171	.129	.124	.101	1.86	1.28	-----	1.02	10.9	9.9	-----	10.1
6	A-C	Corn, barley, oats	3	.183	.123	.122	.108	1.93	1.26	1.30	1.17	10.5	10.2	10.7	10.8
7	A-C	Corn, oats, barley	3	.189	.144	.146	.123	2.05	1.37	1.51	1.27	10.8	9.5	10.3	10.3
9	A-C	Corn, oats, spring wheat	3	.165	.123	.116	.103	1.72	1.23	1.24	1.09	10.4	10.0	10.7	10.6
48	A-C	Sorgo, spring wheat, oats	3	.159	.116	.101	.097	1.67	1.15	1.18	1.03	10.5	9.9	11.7	10.6
Average	-----	-----	-----	.167	.122	.120	.108	1.76	1.22	-----	1.12	10.5	10.0	-----	10.4

## ROW CROP, SMALL GRAIN, SMALL GRAIN (MANURED)

67	A-C	Corn (manured), oats, spring wheat	3	0.177	0.196	0.132	0.114	1.85	2.05	1.34	1.14	10.5	10.5	10.2	10.0
68	A-C	Corn (manured), spring wheat, oats	3	.191	.188	.131	.121	1.93	1.99	-----	1.27	10.1	10.6	-----	10.5
69	A-C	Corn, spring, wheat (manured), oats	3	.154	.176	.118	.112	1.57	1.90	1.21	1.17	10.2	10.8	10.3	10.4
70	A-C	Corn, spring wheat, oats (manured)	3	.200	.196	.135	.124	2.12	2.09	1.45	1.36	10.6	10.7	10.7	11.0
Average	-----	-----	-----	.181	.189	.129	.118	1.87	2.01	-----	1.24	10.3	10.6	-----	10.5

## FALLOW, SMALL GRAIN, SMALL GRAIN

5	A-C	Fallow, spring wheat, oats	3	0.178	0.129	0.135	0.116	1.96	1.32	1.46	1.33	11.0	10.2	10.8	11.5
8	A-C	Fallow, oats, spring wheat	3	.162	.121	.108	.097	1.72	1.14	-----	.95	10.6	9.4	-----	9.8
Average	-----	-----	-----	.170	.125	.121	.107	1.84	1.23	-----	1.14	10.8	9.8	-----	10.7

## ROW CROP, SMALL GRAIN, FALLOW, SMALL GRAIN

18	A-D	Corn, oats, fallow, spring wheat	4	0.156	0.124	0.108	0.098	1.58	1.17	1.10	1.02	10.1	9.4	10.2	10.4
19	A-D	Corn, spring wheat, fallow, oats	4	.165	.118	.115	.103	1.80	1.11	-----	1.02	10.9	9.4	-----	9.9
118	A-D	Corn, oats, fallow, winter wheat	4	.155	.120	.116	.105	1.61	1.22	1.16	1.03	10.4	10.2	10.0	9.8
119	A-D	Corn, winter wheat, fallow, oats	4	.152	.121	.120	.110	1.57	1.25	1.18	1.09	10.3	10.3	9.8	9.9
Average	-----	-----	-----	.157	.121	.115	.104	1.64	1.19	-----	1.04	10.4	9.8	-----	10.0

See footnotes at end of table.

TABLE 34.—Nitrogen and carbon content and carbon/nitrogen ratio of soil from various rotations at Sheridan, Wyo., 1917 and 1947—Con.

## ROW CROP, SMALL GRAIN, RYE (GREEN MANURE), SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Number of plots	Nitrogen at—				Carbon at—				Ratio of carbon to nitrogen at—			
				0 to 6½ inches		6½ to 20 inches		0 to 6½ inches		6½ to 20 inches		0 to 6½ inches		6½ to 20 inches	
				1917	1947	1917	1947	1917	1947	1917	1947	1917	1947	1917	1947
14 <sup>2</sup> .....	A-D.....	Corn, spring wheat, rye (green manure), oats.	4	Percent 0.145	Percent 0.110	Percent 0.110	Percent 0.100	Percent 1.47	Percent 1.01	Percent -----	Percent 0.94	10.1	9.2	-----	9.4
15.....	A-D.....	Corn, oats, rye (green manure), spring wheat.	4	.139	.111	.099	.091	1.40	1.06	0.99	.90	10.1	9.5	10.0	9.9
114.....	A-D.....	Corn, winter wheat, rye (green manure), oats.	4	.159	.130	.130	.127	1.72	1.34	1.32	1.28	10.8	10.3	10.2	10.1
115.....	A-D.....	Corn, oats, rye (green manure), spring wheat.	4	.165	.136	.136	.126	1.76	1.42	1.36	1.25	1.07	10.4	10.0	9.9
Average.....	-----	-----	-----	.152	.122	.119	.111	1.59	1.21	-----	1.09	10.5	9.9	-----	9.8

## ROW CROW, SMALL GRAIN, LEGUME (GREEN MANURE), SMALL GRAIN

16.....	A-D.....	Corn, spring wheat, peas (green manure), oats.	4	0.136	0.112	0.107	0.100	1.37	0.98	1.08	0.94	10.1	8.8	10.1	9.4
17.....	A-D.....	Corn, oats, peas (green manure), spring wheat.	4	.153	.118	.112	.103	1.56	1.10	1.17	1.07	10.2	9.3	10.4	10.4
116 <sup>2</sup> .....	A-D.....	Corn, winter wheat, peas (green manure), oats.	4	.164	.130	.126	.116	1.75	1.29	-----	1.10	10.7	9.9	-----	9.5
117.....	A-D.....	Corn, oats, peas (green manure), winter wheat.	4	.147	.120	.115	.105	1.50	1.16	1.10	1.01	10.2	9.7	9.6	9.6
131 <sup>2</sup> .....	A-D.....	Corn, winter wheat, sweetclover (green manure), oats.	4	.166	.128	.114	.108	1.72	1.26	-----	1.12	10.4	9.8	-----	10.4
132.....	A-D.....	Corn, oats, sweetclover (green manure), winter wheat.	4	.150	.122	.110	.104	1.56	1.19	1.15	1.07	10.4	9.8	10.5	10.3
Average.....	-----	-----	-----	.153	.122	.114	.106	1.58	1.16	-----	1.05	10.3	9.5	-----	9.9

## ROW CROP, SMALL GRAIN, FALLOW (MANURED), SMALL GRAIN

71 <sup>2</sup> -----	A-D-----	Corn, spring wheat, fallow (manured), oats.	4	0.185	0.178	0.127	0.113	1.92	1.91	-----	1.14	10.4	10.7	-----	10.1
72-----	A-D-----	Corn, oats, fallow (manured), spring wheat.	4	.166	.166	.110	.099	1.73	1.78	1.09	1.00	10.4	10.8	9.9	10.1
Average-----	-----	-----	-----	.175	.172	.119	.106	1.83	1.85	-----	1.07	10.5	10.8	-----	10.1

## SMALL GRAIN, FALLOW, FALLOW, FALLOW

570 <sup>4</sup> -----	A-D-----	Spring wheat, fallow, fallow, fallow.	4	0.148	0.096	0.114	0.084	1.52	1.02	1.20	0.90	10.3	10.6	10.5	10.7
------------------------	----------	---------------------------------------	---	-------	-------	-------	-------	------	------	------	------	------	------	------	------

## ROW CROP, FLAX, SMALL GRAIN, FALLOW, SMALL GRAIN

85-----	A-E-----	Corn, flax, barley, fallow, winter wheat.	5	0.190	0.135	0.135	0.117	2.05	1.39	1.41	1.23	10.8	10.3	10.4	10.5
---------	----------	-------------------------------------------	---	-------	-------	-------	-------	------	------	------	------	------	------	------	------

## ROW CROP, SMALL GRAIN, SMALL GRAIN, GRASS, GRASS, GRASS

41 <sup>2</sup> -----	A-F-----	Corn, spring wheat, oats, 3 plots	6	0.159	0.139	0.118	0.108	1.72	1.37	-----	1.08	10.8	9.9	-----	10.0
41-def. <sup>4</sup> -----	A-F-----	grass. do-----	6	.165	.122	.119	.103	1.76	1.26	1.20	1.12	10.7	10.3	10.1	10.9
Average-----	-----	-----	-----	.162	.131	.119	.106	1.74	1.32	1.20	1.10	10.8	10.1	10.1	10.5

## ROW CROP, SMALL GRAIN, SMALL GRAIN, ALFALFA, ALFALFA, ALFALFA

42-def. <sup>3</sup> -----	A-F-----	Corn, spring wheat, oats, 3 plots alfalfa.	6	0.161	0.132	0.108	0.103	1.71	1.26	-----	1.03	10.6	9.5	-----	10.0
----------------------------	----------	-----------------------------------------------	---	-------	-------	-------	-------	------	------	-------	------	------	-----	-------	------

<sup>1</sup> The symbol "M.C." means "Methods of cropping." The symbol "M.F." means "Methods of fallow." The abbreviation "def." signifies "deferred."

<sup>2</sup> The 1917 soils of these rotations were analyzed in Beltsville, Md., and the dry-combustion method was used for the determination of carbon. All the other soils were analyzed at Mandan, N. Dak., and the wet-combustion method was used for the determinations of carbons.

<sup>3</sup> In 1937 these plots were changed to rotation II-258, which is a rotation of spring-plowed oats and winter wheat on disked oat stubble.

<sup>4</sup> Sampled in 1949.

<sup>5</sup> From 1917 to 1936 inclusive, these plots were in M. C. flax plots A to F. Rotation 41 (deferred) is similar to 42 (deferred) except that grass was used instead of alfalfa.

<sup>6</sup> In 1937 this rotation was changed from the standard rotation in which a given plot is in alfalfa for 3 years to the deferred type in which a plot is in alfalfa for 12 years.

TABLE 35.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Archer, Wyo., 1947*

## CONTINUOUS SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. C.-----	A-B-----	Winter wheat—plowed-----	1913	2	0.088	0.079	0.84	0.72	9.5	9.1
M. C.-----	E-F-----	Winter wheat—E subsoiled, F listed-----	1913	2	.097	.089	.90	.78	9.3	8.8
M. C.-----	A-B-----	Spring wheat—plowed-----	1913	2	.086	.092	.90	.87	10.5	9.5
M. C.-----	A-B-----	Oats—plowed-----	1913	2	.094	.094	.86	.84	9.1	8.9
M. C.-----	A-B-----	Barley—plowed-----	1913	2	.086	.088	.84	.82	9.8	9.3
Average-----	-----	-----	-----	-----	.090	.089	.87	.81	9.7	9.1

## ALTERNATE SMALL GRAIN AND FALLOW

M. C.-----	C-D-----	Winter wheat, fallow-----	1913	2	0.082	0.088	0.80	0.74	9.8	8.4
M. C.-----	C-D-----	Spring wheat, fallow-----	1913	2	.082	.081	.78	.73	9.5	9.0
M. C.-----	C-D-----	Oats, fallow-----	1913	2	.082	.087	.76	.74	9.3	8.5
M. C.-----	C-D-----	Barley, fallow-----	1913	2	.079	.081	.72	.74	9.1	9.1
Average-----	-----	-----	-----	-----	.081	.084	.76	.74	9.4	8.8

## CONTINUOUS ROW CROP

M. C. (dup.) <sup>2</sup> -----	A-B-----	Corn—plowed-----	1923	2	0.075	0.082	0.66	0.68	8.8	8.3
M. C.-----	A-B-----	do-----	1913	2	.068	.073	.60	.63	8.8	8.6
M. C.-----	E-F-----	Corn—E subsoiled, F listed-----	1913	2	.073	.079	.65	.71	8.9	9.0
Average-----	-----	-----	-----	-----	.072	.078	.64	.67	8.9	8.6

## ALTERNATE ROW CROP AND FALLOW

M. C. (dup.) <sup>2</sup> -----	C-D-----	Corn, fallow-----	1923	2	0.075	0.080	0.61	0.64	8.1	8.0
M. C.-----	C-D-----	do-----	1913	2	.070	.078	.68	.70	9.7	9.0
Average-----	-----	-----	-----	-----	.072	.079	.64	.67	8.9	8.5

## ROW CROP, SMALL GRAIN, SMALL GRAIN

2-----	A-C-----	Corn, spring wheat, oats-----	1913	3	0.077	0.083	0.76	0.78	9.9	9.4
3-----	A-C-----	do-----	1913	3	.086	.089	.80	.75	9.3	8.4
7-----	A-C-----	Corn, oats, barley-----	1913	3	.074	.090	.73	.76	9.9	9.5
9-----	A-C-----	Corn, oats, spring wheat-----	1913	3	.084	.086	.81	.80	9.6	9.3
Average-----	-----	-----	-----	-----	.080	.084	.78	.78	9.7	9.2

## ROW CROP—MANURED, SMALL GRAIN, SMALL GRAIN

68-----	A-C-----	Corn (manured), spring wheat, oats-----	1913	3	0.099	0.091	0.97	0.81	9.8	8.9
---------	----------	-----------------------------------------	------	---	-------	-------	------	------	-----	-----

## FALLOW, SMALL GRAIN, SMALL GRAIN

8-----	A-C-----	Fallow, oats, spring wheat-----	1913	3	0.083	0.085	0.80	0.73	9.6	8.6
--------	----------	---------------------------------	------	---	-------	-------	------	------	-----	-----

## ROW CROP, SMALL GRAIN, RYE (GREEN MANURE), SMALL GRAIN

14-----	A-D-----	Corn, spring wheat, rye (green manure), oats-----	1913	4	0.085	0.085	0.80	0.76	9.4	8.9
---------	----------	---------------------------------------------------	------	---	-------	-------	------	------	-----	-----

## ROW CROP, SMALL GRAIN, PEAS (GREEN MANURE), SMALL GRAIN

16-----	A-D-----	Corn, spring wheat, peas (green manure), oats-----	1913	4	0.082	0.084	0.80	0.77	9.8	9.2
---------	----------	----------------------------------------------------	------	---	-------	-------	------	------	-----	-----

## ROW CROP, SMALL GRAIN, FALLOW (MANURED), SMALL GRAIN

71-----	A-D-----	Corn, spring wheat, fallow, oats-----	1913	4	0.089	0.088	0.92	0.81	10.3	9.2
72-----	A-D-----	Corn, oats, fallow, spring wheat-----	1913	4	.092	.088	.89	.78	9.7	8.9
Average-----	-----	-----	-----	-----	.091	.088	.90	.80	10.0	9.0

## ROW CROP, POTATOES, BEANS, SMALL GRAIN

7-26-----	A-D-----	Corn, potatoes, beans, spring wheat-----	* 1926	4	0.072	0.079	0.68	0.66	9.4	8.4
-----------	----------	------------------------------------------	--------	---	-------	-------	------	------	-----	-----

See footnotes at end of table.



TABLE 35.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Archer, Wyo., 1947—Continued*  
ROW CROP (MANURED), POTATOES (MANURED), BEANS (MANURED), SMALL GRAIN (MANURED)

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
18-26.....	A-D.....	Corn (manured), potatoes (manured), beans (manured), spring wheat (manured).	<sup>3</sup> 1926	4	0.104	0.080	1.07	0.69	10.3	8.6
19-26.....	A-D.....	do.....	<sup>3</sup> 1926	4	.100	.089	1.02	.80	10.2	9.0
Average.....					.102	.084	1.04	.75	10.2	8.9
ROW CROP, SMALL GRAIN, SMALL GRAIN, GRASS, GRASS, GRASS										
41 <sup>4</sup> .....	A-F.....	Corn, spring wheat, oats, 3 plots grass.....	1913	6	0.085	0.086	0.82	0.80	9.6	9.3
ROW CROP, SMALL GRAIN, SMALL GRAIN, ALFALFA ALFALFA, ALFALFA										
42 <sup>4</sup> .....	A-F.....	Corn, spring wheat, oats, 3 plots alfalfa.....	1913	6	0.079	0.081	0.75	0.76	9.5	9.4
VIRGIN SOD										
None.....		Native grasses.....		9	0.122	0.089	1.33	0.83	10.9	9.3

<sup>1</sup> The symbol "M. C." means "Methods of cropping."<sup>2</sup> From 1913 to 1922, inclusive, the area occupied by the M. C. corn (duplicated plots) was in M. C. flax.<sup>3</sup> From 1912 to 1925, inclusive, the area upon which these rotations are located was used for variety tests alternating with fallow.<sup>4</sup> Changed to deferred type rotation in 1937.

TABLE 36.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Akron, Colo., 1947*  
CONTINUOUS SPRING SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. C. ....	A-B .....	Spring wheat—plowed .....	1908	2	<i>Percent</i> 0.092	<i>Percent</i> 0.085	<i>Percent</i>	<i>Percent</i>		
M. C. ....	A-B .....	Oats—plowed .....	1908	2	.099	.088				
M. C. ....	A-B .....	Barley—plowed .....	1908	2	.100	.090	1.06		10.6	
Average .....					.097	.088				
ALTERNATE SPRING SMALL GRAIN AND FALLOW										
M. C. ....	C-D .....	Spring wheat, fallow .....	1908	2	0.080	0.076				
M. C. ....	C-D .....	Oats, fallow .....	1908	2	.090	.076				
M. C. ....	C-D .....	Barley, fallow .....	1908	2	.094	.080	0.90		9.6	
Average .....					.088	.077				
ALTERNATE WINTER WHEAT AND FALLOW										
267 <sup>2</sup> .....	A-B .....	Winter wheat, fallow .....	1924	2	0.079	0.081				
ALTERNATE WINTER WHEAT AND FALLOW (MANURED)										
268 <sup>2</sup> .....	A-B .....	Winter wheat on manured fallow .....	1924	2	0.102	0.096				
269 <sup>2</sup> .....	A-B .....	Winter wheat (topdressed with manure), fallow .....	1924	2	.099	.092				
Average .....					.100	.094				

See footnotes at end of table.

TABLE 36.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Akron, Colo., 1947—Continued*

## CONTINUOUS ROW CROP

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. O.....	A-B.....	Corn—plowed.....	1908	2	<i>Percent</i> 0.066	<i>Percent</i> 0.070	<i>Percent</i> 0.64	<i>Percent</i> 0.62	9.6	8.9
M. O.....	A-B.....	Kafir—plowed.....	1908	2	.067	.072	.64	.66	9.6	9.2
M. O.....	F.....	Kafir—listed.....	1908	1	.070	.078	.77	.68	11.0	8.7
M. O. <sup>2</sup> .....	A-B.....	Sorgo—plowed.....	1922	2	.068	.074	-----	-----	-----	-----
M. O. <sup>3</sup> .....	A' <sup>4</sup> .....	do.....	1922	1	.079	.078	-----	-----	-----	-----
Average.....	-----	-----	-----	-----	.069	.073	-----	-----	-----	-----

## ALTERNATE ROW CROP AND FALLOW

M. O.....	C-D.....	Corn, fallow.....	1908	2	0.059	0.070	0.55	0.58	9.3	8.3
-----------	----------	-------------------	------	---	-------	-------	------	------	-----	-----

## ALTERNATE ROW CROP AND SMALL GRAIN

252 <sup>1</sup> .....	A-B.....	Corn, winter wheat.....	1924	2	0.086	0.079	-----	-----	-----	-----
------------------------	----------	-------------------------	------	---	-------	-------	-------	-------	-------	-------

## ALTERNATE ROW CROP (MANURED), AND SMALL GRAIN

251 <sup>1</sup> .....	A-B.....	Corn (manured), winter wheat.....	1924	2	0.107	0.085	-----	-----	-----	-----
------------------------	----------	-----------------------------------	------	---	-------	-------	-------	-------	-------	-------

## ROW CROP, SMALL GRAIN, SMALL GRAIN

3.....	A-C.....	Corn, spring wheat, oats.....	1908	3	0.090	0.085	-----	-----	-----	-----
4.....	A-C.....	Corn, oats, spring wheat.....	1908	3	.090	.084	-----	-----	-----	-----
6.....	A-C.....	Corn, barley, oats.....	1908	3	.095	.087	-----	-----	-----	-----
Average.....	-----	-----	-----	-----	.092	.086	-----	-----	-----	-----

## FALLOW, SMALL GRAIN, SMALL GRAIN

5.....	A-C.....	Fallow, spring wheat, oats.....	1908	3	0.089	0.082				
8.....	A-C.....	Fallow, oats, spring wheat.....	1908	3	.083	.075	0.85	0.74	10.2	9.9
Average.....					.086	.078				

## ROW CROP, SMALL GRAIN, FALLOW, SMALL GRAIN

28.....	A-D.....	Corn, oats, fallow, winter wheat.....	1908	4	0.085	0.080				
---------	----------	---------------------------------------	------	---	-------	-------	--	--	--	--

## ROW CROP, SMALL GRAIN, RYE (GREEN MANURE), SMALL GRAIN

51.....	A-D.....	Corn, barley, rye (green manure), winter wheat.....	1908	4	0.084	0.080				
---------	----------	-----------------------------------------------------	------	---	-------	-------	--	--	--	--

## ROW CROP, SMALL GRAIN, PEAS (GREEN MANURE), SMALL GRAIN

92.....	A-D.....	Corn, barley, peas (green manure), winter wheat.....	1908	4	0.090	0.084				
---------	----------	------------------------------------------------------	------	---	-------	-------	--	--	--	--

## VIRGIN SOD

None.....		Native grasses.....		9	0.134	0.087	1.42	0.79	10.5	9.1
-----------	--	---------------------	--	---	-------	-------	------	------	------	-----

<sup>1</sup> The symbol "M. C." means "Methods of cropping."

<sup>2</sup> The land on which these rotations were located was continuously or alternately cropped and fallowed from 1908 to 1923, inclusive.

<sup>3</sup> Sorgo plots were in milo from 1908 to 1921, inclusive.

<sup>4</sup> 1 mark (') on a capital letter means 1 replication of the M. C. plot designated by that letter.

TABLE 37.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations at Colby, Kans., 1916 and 1946*

CONTINUOUS SMALL GRAIN										
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916	1946	1916	1946	1916	1946
M. C.	A-B	Winter wheat	1914	2	Percent	Percent	Percent	Percent	13.1	10.7
M. C.	A-B	Spring wheat	1914	2	.159	.12	2.08	1.28	11.6	11.1
M. C.	A-B	Oats	1914	2	.110	.10	1.28	1.11	9.7	9.5
M. C.	A-B	Barley	1914	2	.122	.12	1.18	1.14	10.5	9.8
Average					.140	.12	1.47	1.18	11.4	9.8
					.132	.12	1.50	1.18	11.4	9.8

ALTERNATE SMALL GRAIN AND FALLOW										
M. C.	C-D	Winter wheat—spring-plowed	1914	2	0.148	0.11	1.78	1.07	12.0	9.7
M. F.	H-I	Winter wheat—fall-plowed	1914	2	.167	.11	1.63	1.15	9.8	10.4
M. F.	J-K	do	1914	2	.165	.12	1.76	1.20	10.7	10.0
M. F.	L-M	Winter wheat—plowed in May	1914	2	.168	.12	1.70	1.28	10.1	10.7
M. F.	N-O	Winter wheat—plowed in June	1914	2	.165	.12	1.81	1.32	11.0	11.0
M. F.	P-Q	Winter wheat—fall-listed	1914	2	.161	.12	1.88	1.28	11.7	10.7
267.	A	Winter wheat—spring-plowed		1		.11		1.00		9.1
M. C.	C-D	Spring wheat—spring-plowed	1914	2	.118	.10	1.35	1.04	11.4	10.4
M. C.	C-D	Oats—spring-plowed	1914	2	.116	.10	1.14	.98	9.8	9.8
M. C.	C-D	Barley—spring-plowed	1914	2	.118	.10	1.12	.98	9.5	9.8
Average					.147	.11	1.57	1.13	10.7	10.3

CONTINUOUS ROW CROP										
M. C.	A-B	Corn—plowed	1914	2		0.08		0.68		8.5
M. C.	A-B	Kafir—plowed	1914	2	0.114	.08	1.31	.78	11.5	9.8
M. C.	A-B	Milo—plowed	1914	2		.09		.79		8.8
Average						.08		.75		9.4

## ALTERNATE ROW CROP AND FALLOW

M. C.	C-D	Corn, fallow	1914	2		0.08		0.69		8.6
M. C.	C-D	Kafir, fallow	1914	2	0.107	.08	1.18	.66	11.0	8.2
M. C.	C-D	Milo, fallow	1914	2		.08		.68		8.5
Average						.08		.68		8.5

## ROW CROP, SMALL GRAIN, SMALL GRAIN

6.	A-C	Corn, barley, oats	1914	3	0.156	0.12	1.90	1.15	12.2	9.6
7.	A-C	Corn, oats, barley	1914	3	.155	.12	1.84	1.23	11.9	10.2
9.	A-C	Corn, oats, spring wheat	1914	3	.153	.11	2.07	1.15	13.5	10.4
Average					.155	.12	1.94	1.18	12.5	9.8

## FALLOW, SMALL GRAIN, SMALL GRAIN—STUBBLE NOT BURNED

8.	A-C	Fallow, oats, spring wheat	1914	3	0.125	0.11	1.33	1.06	10.6	9.6
568.	A-C	Fallow, winter wheat, winter wheat		3		.11		.99		9.0
Average						.11		1.02		9.3

## FALLOW, SMALL GRAIN, SMALL GRAIN—STUBBLE BURNED

121-1	A-C	Fallow, winter wheat, winter wheat		3		0.10		0.92		9.2
122-2	A-C	do		3		.09		.91		10.1
Average						.10		.92		9.2

## FALLOW, SMALL GRAIN, ROW CROP

551.	A-C	Fallow, winter wheat, milo	1914	3	0.130	0.10	1.34	0.92	10.3	9.2
552.	A-C	do	1914	3	.118	.09	1.18	.87	10.0	9.7
553.	A-C	do	1914	3	.137	.11	1.21	.96	8.8	8.7
Average					.128	.10	1.24	.92	9.7	9.2

See footnote at end of table.

TABLE 37.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations at Colby, Kans., 1916 and 1946—Continued*

FALLOW, SMALL GRAIN (TOPDRESSED WITH 3 TONS PER ACRE OF STRAW), ROW CROP										
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916	1946	1916	1946	1916	1946
554.....	A-C.....	Fallow, winter wheat plus straw, milo.....	1914	3	Percent 0.120	Percent 0.11	Percent 1.25	Percent 1.01	10.4	9.2
FALLOW, SMALL GRAIN, ROW CROP (3 TONS PER ACRE OF MANURE)										
555.....	A-C.....	Fallow, winter wheat (topdressed with manure), milo.....	1914	3	0.119	0.10	1.28	0.94	10.8	9.4
557.....	A-C.....	Fallow, winter wheat, milo (manured).....	1914	3	.130	.10	1.33	.95	10.2	9.5
Average.....					.125	.10	1.30	.94	10.4	9.4
FALLOW, SMALL GRAIN, ROW CROP (TOPDRESSED WITH 6 TONS PER ACRE OF MANURE)										
556.....	A-C.....	Fallow, winter wheat (manured), milo.....	1914	3	0.125	0.10	1.28	0.93	10.2	9.3
558.....	A-C.....	Fallow, winter wheat, milo (manured).....	1914	3	.124	.11	1.31	1.01	10.6	9.2
Average.....					.124	.10	1.30	.97	10.5	9.7
FALLOW, SMALL GRAIN, ROW CROP (TOP DRESSED WITH 9 TONS PER ACRE OF MANURE)										
559.....	A-C.....	Fallow, winter wheat, milo (manured).....	1914	3	0.139	0.11	1.37	1.08	9.9	9.8
FALLOW, SMALL GRAIN, ROW CROP (TOP DRESSED WITH 12 TONS PER ACRE OF MANURE)										
560.....	A-C.....	Fallow, winter wheat, milo (manured).....	1914	3	0.139	0.12	1.37	1.11	9.9	9.2

## ROW CROP, ROW CROP, SMALL GRAIN, RYE (GREEN MANURE)

152-----	A-D-----	Milo, corn, winter wheat, rye (green manure)-----	1914	4	0.130	0.09	1.60	0.86	12.3	9.6
153-----	A-D-----	Corn, milo, rye (green manure), winter wheat-----	1914	4	.116	.10	1.43	.94	12.3	9.4
Average-----	-----	-----	-----	-----	.123	.10	1.52	.90	12.4	9.0

## ROW CROP, FALLOW, SMALL GRAIN, RYE (GREEN MANURE)

151-----	A-D-----	Milo, fallow, winter wheat, rye (green manure)-----	1914	4	0.124	0.09	1.33	0.88	10.7	9.8
----------	----------	-----------------------------------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, FALLOW, SMALL GRAIN, PEAS (GREEN MANURE)

154-----	A-D-----	Milo, fallow, winter wheat, peas (green manure)-----	1914	4	0.143	0.10	1.64	0.93	11.5	9.3
----------	----------	------------------------------------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, FALLOW, SMALL GRAIN, FALLOW

155-----	A-D-----	Milo, fallow, winter wheat, fallow-----	1914	4	0.138	0.10	1.56	0.98	11.3	9.8
----------	----------	-----------------------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, FALLOW, SMALL GRAIN, FALLOW (10 TONS PER ACRE OF MANURE)

156-----	A-D-----	Milo, fallow, winter wheat, fallow (manured)-----	-----	4	0.147	0.12	1.85	1.16	12.6	9.7
----------	----------	---------------------------------------------------	-------	---	-------	------	------	------	------	-----

## VIRGIN SOD

Weather station-----	-----	Native grass-----	-----	1	0.182	0.18	2.00	2.06	11.0	11.4
Grid-----	-----	do-----	-----	9	-----	.163	-----	1.80	-----	11.1
Weighted average-----	-----	-----	-----	10	-----	.165	-----	1.83	-----	11.1

<sup>1</sup> The symbol "M. C." means "Methods of cropping." The symbol "M. F." means "Methods of fallow."



TABLE 38.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations at Hays, Kans., 1916 and 1946*

CONTINUOUS SMALL GRAIN										
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916	1946	1916	1946	1916	1946
					<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>		
M. C	A-B	Winter wheat—plowed.....	1906	2	0.162	0.14	1.88	1.52	11.6	10.8
M. C	E-F	Winter wheat—E subsoiled, F listed.....	1906	2	.156	.14	1.75	1.42	11.2	10.1
591	A	Winter wheat—stubble-in.....	1913	1	.168	.16	1.85	1.72	11.0	10.8
606	A	Winter wheat—plowed.....	1916	1	.167	.13	1.95	1.26	11.7	9.7
606	B	Winter wheat—alternately plowed and disked.....	1916	1	.167	.13	1.94	1.35	11.6	10.4
606	C	Winter wheat—plowed 1 year, disked 2 years.....	1916	1	.172	.14	1.91	1.37	11.1	9.8
606	D	Winter wheat—plowed 1 year, disked 3 years.....	1916	1	.169	.14	1.91	1.38	11.3	9.9
606	E	Winter wheat—plowed 1 year, disked 4 years.....	1916	1	.169	.15	1.95	1.52	11.5	10.1
606	F	Winter wheat—plowed when necessary.....	1916	1	.166	.15	1.89	1.44	11.4	9.6
M. C	A-B	Oats—plowed.....	1906	2	.145	.13	1.78	1.33	12.3	10.2
M. C	E-F	Oats—E subsoiled, F listed.....	1906	2	.128	.12	1.48	1.16	11.6	9.7
M. C	A-B	Barley—plowed.....	1906	2	.150	.14	1.96	1.31	13.1	9.4
M. C	E-F	Barley—E subsoiled, F listed.....	1906	2	.149	.12	1.82	1.24	12.2	10.3
Average					.156	.14	1.83	1.37	11.7	9.8
ALTERNATE SMALL GRAIN AND FALLOW										
M. C	C-D	Winter wheat—plowed May 15.....	1906	2	0.145	0.14	1.66	1.37	11.4	9.8
M. F	I	Winter wheat—fall-plowed, replowed in spring.....	1914	1	.149	.11	1.72	1.04	11.5	9.4
M. F	K	Winter wheat—fall-plowed.....	1914	1	.151	.12	1.81	1.06	12.0	8.8
M. F	M	Winter wheat—plowed in May.....	1914	1	.155	.14	1.87	1.34	12.1	9.6
M. F	O	Winter wheat—plowed in June.....	1914	1	.164	.14	1.90	1.40	11.6	10.0
M. F	Q	Winter wheat—fall-listed.....	1914	1	.168	.13	1.97	1.28	11.7	9.8
M. C	C-D	Oats—plowed May 15.....	1906	2	.120	.11	1.28	1.05	10.7	9.6
M. C	C-D	Barley—plowed May 15.....	1906	2	.120	.11	1.54	1.12	12.8	10.2
Average					.142	.12	1.66	1.20	11.7	10.0

## CONTINUOUS ROW CROP

M. C. ....	H-B. ....	Kafir—plowed .....	1910	2	0.140	0.10	1.64	0.94	11.7	9.4
M. C. ....	E-F. ....	Kafir—E subsoiled, F listed .....	1910	2	.152	.10	1.94	1.05	12.8	10.5
M. C. ....	G. ....	Kafir—lister-planted .....	1910	1	.144	.10	1.87	1.00	13.0	10.0
M. C. ....	H-B. ....	Milo—plowed .....	1910	2	.144	.10	1.78	1.00	12.4	10.0
M. C. ....	E-F. ....	Milo—E subsoiled, F listed .....	1910	2	.160	.10	1.66	1.06	10.4	10.6
M. C. ....	G. ....	Milo—lister-planted .....	1910	1	.161	.10	1.66	1.08	10.3	10.8
Average .....	.....	.....	.....	.....	.149	.10	1.76	1.02	11.8	10.2

## ALTERNATE ROW CROP AND FALLOW

M. C. ....	C-D. ....	Kafir, fallow .....	1910	2	0.142	0.08	1.72	0.86	12.1	10.8
M. C. ....	C-D. ....	Milo, fallow .....	1910	2	.150	.09	1.92	.90	12.8	10.0
Average .....	.....	.....	.....	.....	.146	.09	1.82	.88	12.5	9.8

## ROW CROP, SMALL GRAIN

150. ....	A-B. ....	Corn—80-inch rows, winter wheat .....	1915	2	0.180	0.13	1.96	1.34	10.9	10.3
350. ....	A-B. ....	Kafir—80-inch rows, winter wheat .....	1915	2	.174	.12	1.81	1.14	10.4	9.5
149. ....	A-B. ....	Corn—40-inch rows, winter wheat .....	1916	2	.172	.12	2.03	1.27	11.8	10.6
349. ....	A-B. ....	Kafir—40-inch rows, winter wheat .....	1915	2	.168	.12	1.98	1.10	11.8	9.2
Average .....	.....	.....	.....	.....	.174	.12	1.94	1.21	11.2	10.1

## ROW CROP, SMALL GRAIN, SMALL GRAIN

1. ....	A-C. ....	Corn, spring wheat, oats .....	1906	3	0.143	0.11	1.58	1.12	11.0	10.2
9. ....	A-C. ....	Corn, oats, spring wheat .....	1906	3	.149	.13	1.69	1.34	11.3	10.3
58. ....	A-C. ....	Sorgo, oats, spring wheat .....	1906	3	.154	.13	1.70	1.27	11.0	9.8
Average .....	.....	.....	.....	.....	.149	.12	1.65	1.24	11.1	10.3

See footnotes at end of table.

TABLE 38.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations at Hays, Kans., 1916 and 1946—Continued*

ROW CROP, FALLOW, SMALL GRAIN										
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916	1946	1916	1946	1916	1946
					Percent	Percent	Percent	Percent		
501.....	A-C.....	Kafir, fallow, winter wheat.....	1913	3	0.134	0.10	1.31	0.97	9.8	9.7
502.....	A-C.....	do.....	1913	3	.163	.12	1.72	1.16	10.6	9.7
503.....	A-C.....	do.....	1913	3	.162	.11	1.78	1.13	11.0	10.3
551.....	A-C.....	do.....	1913	3	.170	.11	1.87	1.08	11.0	9.8
552.....	A-C.....	do.....	1913	3	.171	.11	1.78	1.07	10.4	9.7
553.....	A-C.....	do.....	1913	3	.168	.11	1.77	1.08	10.5	9.8
Average.....					.161	.11	1.71	1.08	10.6	9.8
ROW CROP, FALLOW, SMALL GRAIN (3 TONS PER ACRE OF STRAW)										
554.....	A-C.....	Kafir, fallow, winter wheat (3 tons per acre of straw).....	1913	3	0.170	0.11	1.75	1.13	10.3	10.3
ROW CROP, FALLOW, SMALL GRAIN (3 TONS PER ACRE OF MANURE)										
555.....	A-C.....	Kafir, fallow, winter wheat (3 tons per acre manure).....	1913	3	0.174	0.12	1.78	1.14	10.2	9.5
557.....	A-C.....	Kafir (3 tons per acre of manure) fallow, winter wheat.....	1913	3	.174	.12	1.84	1.14	10.6	9.5
Average.....					.174	.12	1.81	1.14	10.4	9.5
ROW CROP, FALLOW, SMALL GRAIN (6 TONS PER ACRE OF MANURE)										
556.....	A-C.....	Kafir, fallow, winter wheat (6 tons per acre of manure).....	1913	3	0.179	0.11	1.96	1.18	11.0	10.7
558.....	A-C.....	Kafir (6 tons per acre of manure), fallow, winter wheat.....	1913	3	.177	.13	1.92	1.31	10.8	10.1
Average.....					.178	.12	1.94	1.24	10.9	10.3

## ROW CROP (9 TONS PER ACRE OF MANURE), FALLOW, SMALL GRAIN

559.....	A-C.....	Kafir (9 tons per acre of manure), fallow, winter wheat.....	1913	3	0.177	0.13	1.91	1.35	10.8	10.4
----------	----------	--------------------------------------------------------------	------	---	-------	------	------	------	------	------

## ROW CROP (12 TONS PER ACRE OF MANURE), FALLOW, SMALL GRAIN

560.....	A-C.....	Kafir (12 tons per acre of manure), fallow, winter wheat.....	1913	3	0.180	0.14	1.92	1.47	10.7	10.5
----------	----------	---------------------------------------------------------------	------	---	-------	------	------	------	------	------

## ROW CROP, SMALL GRAIN, SMALL GRAIN, SMALL GRAIN

403.....	A-D.....	Corn, barley, winter wheat, winter wheat.....	1916	4	0.166	0.12	1.84	1.22	11.1	10.2
404.....	A-D.....	Kafir, barley, winter wheat, winter wheat.....	1916	4	.177	.13	2.04	1.38	11.5	10.6
Average.....	.....	.....	.....	.....	.172	.13	1.94	1.30	11.3	10.0

## SMALL GRAIN, FALLOW, FALLOW, FALLOW

570.....	A-D.....	Winter wheat, fallow, fallow, fallow.....	1915	4	0.168	0.11	1.84	1.08	11.0	9.8
----------	----------	-------------------------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, SMALL GRAIN, FALLOW, SMALL GRAIN

57.....	A-D.....	Corn, barley, fallow, winter wheat.....	1906	4	0.147	0.12	1.58	1.11	10.8	9.2
---------	----------	-----------------------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, SMALL GRAIN, RYE (GREEN MANURE), SMALL GRAIN

51.....	A-D.....	Corn, barley, rye (green manure), winter wheat.....	1906	4	0.167	0.14	1.95	1.38	11.7	9.9
53.....	A-D.....	Corn, winter wheat, rye (green manure), barley.....	1906	4	.162	.14	2.02	1.40	12.5	10.0
55.....	A-D.....	Kafir, barley, rye (green manure), winter wheat.....	1906	4	.157	.13	1.82	1.33	11.6	10.2
Average.....	.....	.....	.....	.....	.162	.14	1.93	1.37	11.9	9.8

## ROW CROP, SMALL GRAIN, PEAS (GREEN MANURE), SMALL GRAIN

54.....	A-D.....	Corn, winter wheat, peas (green manure), barley.....	1906	4	0.152	0.13	1.68	1.26	11.0	9.7
92.....	A-D.....	Corn, barley, peas (green manure), winter wheat.....	1906	4	.162	.13	1.79	1.22	11.0	9.4
56.....	A-D.....	Kafir, barley, peas (green manure), winter wheat.....	1906	4	.155	.13	1.83	1.27	11.8	9.8
Average.....	.....	.....	.....	.....	.157	.13	1.77	1.25	11.3	9.6

See footnotes at end of table.

TABLE 38.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations at Hays, Kans., 1916 and 1946—Continued*

ALTERNATE SMALL GRAIN AND FALLOW <sup>1</sup>										
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916	1946	1916	1946	1916	1946
M. F.....	H.....	Winter wheat—fall-plowed, replowed in spring.....	1914	1	Percent	Percent	Percent	Percent		10.2
M. F.....	J.....	Winter wheat—fall-plowed.....	1914	1	-----	0.11	-----	1.12	-----	10.0
M. F.....	L.....	Winter wheat—plowed in May.....	1914	1	-----	.12	-----	1.20	-----	10.4
M. F.....	N.....	Winter wheat—plowed in June.....	1914	1	-----	.13	-----	1.25	-----	10.2
M. F.....	P.....	Winter wheat—fall-listed.....	1914	1	-----	.13	-----	1.32	-----	9.7
Average.....		-----			-----	.12	-----	1.23	-----	10.2
SMALL GRAIN—STUBBLE BURNED <sup>2</sup>										
C15.....	7.....	Continuous winter wheat—stubble burned.....	1919	1	-----	0.14	-----	1.46	-----	10.4
C14, C16.....	7.....	Continuous winter wheat—stubble burned in alternate years.....	1919	2	-----	.13	-----	1.42	-----	10.9
C9, C13.....	7.....	Fallow, winter wheat, wheat on burned stubble, wheat, wheat.....	1919	2	-----	.12	-----	1.24	-----	10.3
Average.....		-----			-----	.13	-----	1.35	-----	10.3
SMALL GRAIN—STUBBLE NOT BURNED <sup>2</sup>										
C15.....	8.....	Continuous winter wheat—stubbled-in.....	1919	1	-----	0.14	-----	1.57	-----	11.2
C14, C16.....	8.....	Continuous winter wheat—stubbled-in in alternate years.....	1919	2	-----	.13	-----	1.39	-----	10.7
C9, C13.....	8.....	Fallow, winter wheat, wheat stubbled-in, wheat, wheat.....	1919	2	-----	.12	-----	1.23	-----	10.2
Average.....		-----			-----	.13	-----	1.36	-----	10.5
ROW CROP, FALLOW, SMALL GRAIN, SMALL GRAIN <sup>2</sup>										
401.....	A-D.....	Kafir, fallow, winter wheat, winter wheat.....	1913	4	-----	0.11	-----	1.08	-----	9.8

ROW CROP, ROW CROP, FALLOW, SMALL GRAIN <sup>1</sup>

402.....	A-D.....	Kafir, kafir, fallow, winter wheat.....	1913	4	-----	0.10	-----	0.96	-----	9.6
----------	----------	-----------------------------------------	------	---	-------	------	-------	------	-------	-----

ROW CROP, FALLOW, SMALL GRAIN <sup>1</sup>

504.....	A-C.....	Kafir, fallow, winter wheat.....	1913	3	-----	0.11	-----	1.08	-----	9.8
505.....	A-C.....	do.....	1913	3	-----	.11	-----	1.05	-----	9.5
506.....	A-C.....	do.....	1913	3	-----	.11	-----	1.06	-----	9.6
507.....	A-C.....	do.....	1913	3	-----	.11	-----	1.05	-----	9.5
508.....	A-C.....	do.....	1913	3	-----	.11	-----	1.06	-----	9.6
509.....	A-C.....	do.....	1913	3	-----	.11	-----	1.08	-----	9.8
510.....	A-C.....	do.....	1913	3	-----	.11	-----	1.14	-----	10.4
Average.....	-----	-----	-----	-----	-----	.11	-----	1.08	-----	9.8

VIRGIN SOD <sup>2</sup>

Fort Hays pasture.....	-----	(Native grass.....	-----	1	-----	0.22	-----	2.54	-----	11.5
Virgin grid.....	-----	do.....	-----	1	-----	.22	-----	2.44	-----	11.1
Weighted average.....	-----	do.....	-----	9	-----	.22	-----	2.47	-----	11.2
	-----	-----	-----	-----	-----	.22	-----	2.47	-----	11.2

SOD REESTABLISHED IN 1911 <sup>2</sup>

None.....	-----	Native grass.....	-----	1	-----	0.20	-----	1.92	-----	9.6
-----------	-------	-------------------	-------	---	-------	------	-------	------	-------	-----

<sup>1</sup> The symbol "M. C." means "Methods of cropping." The symbol "M. F." means "Methods of fallow." The symbol "C" means "Continuous."<sup>2</sup> Plots and rotations not sampled prior to 1946.

TABLE 39.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations in the main field at Garden City, Kans., 1916 and 1946*

## CONTINUOUS SMALL GRAINS

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916 <sup>2</sup>	1946	1916	1946	1916	1946
					Percent	Percent	Percent	Percent		
M. C.-----	A-B-----	Winter wheat—plowed-----	1908	2	0.110	0.10	1.46	0.90	13.3	9.0
M. O.-----	E-F-----	Winter wheat—E subsoiled, F listed-----	1908	2	.100	.09	1.14	.78	11.4	8.7
M. O. <sup>3</sup> -----	B-----	Oats—plowed-----	1922	1	.094	.08	.96	.72	10.2	9.0
M. O. <sup>3</sup> -----	B-----	Barley—plowed-----	1922	1	.093	.09	1.07	.78	11.6	8.7
Average-----	-----	-----	-----	-----	.101	.09	1.20	.81	11.9	9.0

## ALTERNATE SMALL GRAIN AND FALLOW

M. O.-----	C-D-----	Winter wheat—spring-plowed-----	1908	2	0.090	0.08	1.16	0.74	12.9	9.2
M. F.-----	H-I-----	Winter wheat—fall-plowed, replowed in spring-----	1913	2	.083	.08	.84	.68	10.1	8.5
M. F.-----	J-K-----	Winter wheat—fall-plowed-----	1913	2	.088	.08	.90	.72	10.2	9.0
M. F.-----	L-M-----	Winter wheat—plowed in May-----	1913	2	.096	.08	.99	.82	10.3	10.2
M. F.-----	N-O-----	Winter wheat—plowed in June-----	1913	2	.100	.09	1.14	.84	11.4	9.3
M. F.-----	P-Q-----	Winter wheat—fall-listed-----	1913	2	.092	.08	1.00	.73	10.9	9.1
Average-----	-----	-----	-----	-----	.092	.08	1.00	.75	10.9	9.4

## CONTINUOUS ROW CROPS

M. C.-----	A-B-----	Corn—plowed-----	1908	2	0.079	0.06	0.88	0.54	11.1	9.0
M. C.-----	E-F-----	Corn—E subsoiled, F listed-----	1908	2	.084	.06	.74	.57	8.8	9.6
M. C.-----	G-----	Corn—listed-planted-----	1908	1	.083	.07	.73	.55	8.8	7.9
M. C.-----	A-B-----	Kafr—plowed-----	1908	2	.084	.06	.77	.62	9.2	10.3
M. C.-----	F-----	Kafr—listed-----	1908	1	.091	.06	.88	.60	9.7	10.0
M. C.-----	A-B-----	Milo—plowed-----	1908	2	.088	.07	1.08	.64	12.3	9.1
M. C.-----	F-----	Milo—listed-----	1908	1	.085	.07	.97	.64	11.4	9.1
S. B.-----	1, 3-----	Kafr-----	1913	2	.113	.06	1.40	.51	12.9	8.6
S. B.-----	2, 4-----	do-----	1913	2	.124	.06	1.54	.60	12.4	10.0
S. B.-----	17, 18-----	Sorgo-----	1913	2	.123	.07	1.38	.59	11.2	8.4
Average-----	-----	-----	-----	-----	.097	.07	1.08	.58	11.1	8.3

## ALTERNATE ROW CROP AND FALLOW

M. C.	C-D	Corn—spring-plowed	1908	2	0.082	0.06	0.90	0.54	11.0	9.0
-------	-----	--------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, ROW CROP, SUDAN

213.	A-C	Kafir, milo Sudangrass	1916	3	0.110	0.08	1.12	0.75	10.2	9.4
------	-----	------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, COWPEAS, SUDANGRASS

83.	A-C	Kafir, cowpeas, Sudangrass		3	0.091	0.07	0.99	0.62	10.9	8.9
-----	-----	----------------------------	--	---	-------	------	------	------	------	-----

## ROW CROP, FALLOW, SMALL GRAIN

405.	A-C	Kafir, fallow, winter wheat	1913	3	0.096	0.08	1.11	0.74	11.6	9.2
------	-----	-----------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, FALLOW, SMALL GRAIN, SMALL GRAIN

324.	A-D	Kafir, fallow, winter wheat, winter wheat	1913	4	0.098	0.08	1.14	0.78	11.6	9.8
------	-----	-------------------------------------------	------	---	-------	------	------	------	------	-----

## ROW CROP, FALLOW, SMALL GRAIN, SMALL GRAIN, RYE (GREEN MANURE)

331.	A-E	Kafir, fallow, winter wheat, winter wheat, rye (green manure)	1913	5	0.099	0.09	1.05	0.71	10.6	7.9
332.	A-E	Kafir, fallow, winter wheat, rye (green manure), winter wheat	1913	5	.108	.08	1.22	.76	11.3	9.5
Average					.103	.08	1.14	.74	11.1	9.2

## CONTINUOUS SMALL GRAIN :

S. B.	1-2	Winter wheat—plowed		2		0.09		0.70		7.8
S. B.	5-6	do		2		.08		.67		8.4
M. C.	B.	Spring wheat—plowed	1922	1		.09		.76		8.4
Average						.09		.70		7.8

See footnotes at end of table.



TABLE 39.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations in the main field at Garden City, Kans., 1916 and 1946—Continued*

ALTERNATE SMALL GRAIN AND FALLOW 3										
Rotation 1	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1916	1946	1916	1946	1916	1946
S. B.....	3-4.....	Winter wheat.....		2	Percent	Percent 0.08	Percent	Percent 0.62		7.8
CONTINUOUS ROW CROP										
S. B.....	5-6.....	Kafir.....	1913	2		0.07		0.57		8.1
ALTERNATE ROW CROP AND FALLOW (5 TONS PER ACRE OF MANURE) 3										
298.....	A-B.....	Milo, fallow (5 tons per acre of manure).....	1921	2		0.07		0.54		7.7
302.....	A-B.....	Milo (5 tons per acre of manure), fallow.....	1921	2		.08		.60		7.5
Average.....						.07		.57		8.1
ROW CROP, COWPEAS 3										
295.....	A-B.....	Milo, cowpeas.....	1921	2		0.07		0.54		7.7
ROW CROP (MANURED), COWPEAS 3										
301.....	A-B.....	Milo (topdressed with manure), cowpeas.....	1921	2		0.07		0.62		8.9
FALLOW, WINTER WHEAT, WINTER WHEAT ON BURNED STUBBLE 3										
121.....	A-C.....	Fallow, winter wheat, winter wheat on burned stubble.....	1921	3		0.07		0.65		9.3

FALLOW, WINTER WHEAT, WINTER WHEAT ON STUBBLE NOT BURNED <sup>1</sup>

567.....	A-C.....	Fallow, winter wheat, winter wheat on stubble not burned...	1921	3	-----	0.08	-----	0.70	-----	8.8
----------	----------	-------------------------------------------------------------	------	---	-------	------	-------	------	-------	-----

## VIRGIN SOD

None.....	East fence line....	Native grass.....	-----	-----	-----	0.12	-----	1.13	-----	9.4
-----------	---------------------	-------------------	-------	-------	-------	------	-------	------	-------	-----

<sup>1</sup> The symbol "M. C." means "Methods of cropping." The symbol "M. F." means "Methods of fallow." The symbol "S. B." means "Seedbed."

<sup>2</sup> These plots were in rotation from 1908 to 1921, inclusive.

<sup>3</sup> Plots and rotations not sampled prior to 1946.

TABLE 40.—*Nitrogen and carbon content and carbon/nitrogen ratio of the 0- to 7-inch depth of soil under various rotations in the annex at Garden City, Kans., 1931 and 1946*

CONTINUOUS SMALL GRAIN										
Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen		Carbon		Ratio of carbon to nitrogen	
					1931	1946	1931	1946	1931	1946
S. S. ....	1.....	Winter wheat—stubble burned, plowed.....	1931	1	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	10.4	9.8
571.....	A.....	Winter wheat—stubbled-in.....	1931	1	.149	.12	1.44	1.06	9.7	8.8
S. B. ....	1, 2.....	Winter wheat—listed.....	1931	2	.137	.11	1.44	1.07	10.5	9.7
S. B. ....	3, 4, 6.....	Winter wheat—plowed.....	1931	3	.134	.12	1.41	1.09	10.5	9.1
S. B. ....	5, 7.....	Winter wheat—one-wayed.....	1931	2	.133	.11	1.37	1.07	10.3	9.7
Average.....	.....	.....	.....	.....	.138	.11	1.43	1.08	10.4	9.8
ALTERNATE SMALL GRAIN AND FALLOW										
267.....	A-B.....	Winter wheat.....	1931	2	0.146	0.11	1.44	1.00	9.9	9.1
CONTINUOUS ROW CROP										
S. S. ....	2.....	Milo—listed.....	1931	1	0.141	0.10	1.44	0.90	10.2	9.0
SMALL GRAIN, RYE (GREEN MANURE)										
S. S. ....	4.....	Winter wheat, rye (green manure).....	1931	1	0.146	0.11	1.48	1.03	10.1	9.4
SMALL GRAIN, COWPEAS (GREEN MANURE)										
S. S. ....	5.....	Winter wheat, cowpeas (green manure).....	1931	1	0.145	0.11	1.50	0.98	10.3	8.9

## FALLOW, SMALL GRAIN, ROW CROP

S. S.-----	3-----	Fallow, winter wheat, mlo-----	1931	1	0.136	0.10	1.34	0.87	9.9	8.7
------------	--------	--------------------------------	------	---	-------	------	------	------	-----	-----

## FALLOW, SMALL GRAIN, SMALL GRAIN

567-----	A-C-----	Fallow, winter wheat, winter wheat-----	1931	3	0.142	0.11	1.45	1.01	10.2	9.2
----------	----------	-----------------------------------------	------	---	-------	------	------	------	------	-----

## FALLOW, SMALL GRAIN, SMALL GRAIN, SMALL GRAIN

566-----	A-D-----	Fallow, winter wheat, winter wheat, winter wheat-----	1931	4	0.135	0.10	1.37	0.97	10.1	9.7
----------	----------	-------------------------------------------------------	------	---	-------	------	------	------	------	-----

## VIRGIN SOD

N. P.-----	-----	Native grass-----	-----	-----	-----	0.12	-----	1.20	-----	10.0
------------	-------	-------------------	-------	-------	-------	------	-------	------	-------	------

1 The symbol "S. S." means "Soil studies." The symbol "S. B." means "Seedbed." The symbol "N. P." means "North pasture."

TABLE 41.—*Nitrogen and carbon content and carbon/nitrogen ratio of soil under various rotations at Woodward, Okla., 1947*

## CONTINUOUS ROW CROP

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen at—	
					0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches	0 to 6 inches	6 to 12 inches
M. C	A-B	Corn—plowed	1914	2	<i>Percent</i> 0.036	<i>Percent</i> 0.042	<i>Percent</i> 0.38	<i>Percent</i> 0.40	10.6	9.5
M. C	A-B	Milo—plowed	1914	2	.032	.042	.34	.40	10.6	9.5
M. C	B' <sup>2</sup>	do	1918	1	.026	.034	.25	.32	9.6	9.4
M. C	A-B	Kafir—plowed	1914	2	.032	.044	.34	.44	10.6	10.0
M. C	A-B	Broomcorn—plowed	1914	2	.028	.038	.30	.40	10.7	10.5
M. C	A-B	Sorgo—plowed	1914	2	.028	.038	.30	.37	10.7	9.7
Average					.031	.040	.32	.39	10.3	9.8

## CONTINUOUS ROW CROP (MANURED)

M. C	T	Milo (manured)	1918	1	0.035	0.038	0.40	0.37	11.4	9.7
M. C	T	Kafir (manured)	1918	1	.042	.046	.43	.49	10.2	10.6
Average					.038	.042	.42	.43	11.0	10.2

## ALTERNATE ROW CROP AND FALLOW

M. C	C-D	Corn, fallow	1914	2	0.028	0.034	0.26	0.32	9.3	9.4
M. C	C-D	Milo, fallow	1914	2	.024	.031	.24	.29	10.0	9.4
297	A-B	do	1918	2	.025	.031	.26	.30	10.4	9.7
M. C	C-D	Kafir, fallow	1914	2	.026	.034	.27	.31	10.4	9.1
M. C	C-D	Broomcorn, fallow	1914	2	.028	.034	.32	.35	11.4	10.3
M. C	C-D	Sorgo, fallow	1914	2	.022	.030	.23	.29	10.4	9.7
Average					.026	.032	.26	.31	10.0	9.7

## ROW CROP AND COWPEAS

285.....	A-B.....	Kafir, cowpeas.....	1918	2	0.022	0.038	0.22	0.36	10.0	9.5
----------	----------	---------------------	------	---	-------	-------	------	------	------	-----

## ROW CROP AND COWPEAS (GREEN MANURE)

286.....	A-B.....	Kafir, cowpeas (green manure).....	1918	2	0.028	0.034	0.29	0.34	10.4	10.0
----------	----------	------------------------------------	------	---	-------	-------	------	------	------	------

<sup>1</sup> The symbol "M. C." means "Methods of cropping."

<sup>2</sup> 1 mark (') on a capital letter means 1 replication of the M. C. plot designated by that letter.

TABLE 42.—*Nitrogen content of soil under various rotations at Lawton, Okla., 1947*  
CONTINUOUS SMALL GRAIN—PLOWED OR LISTED

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—	
					0 to 6 inches	6 to 12 inches
					<i>Percent</i>	<i>Percent</i>
261.....	A.....	Winter wheat, oats.....	1919	1	0.080	0.086
S. L.....	1, 2.....	Winter wheat—plowed.....	1923	2	.088	.090
S. L.....	3, 4.....	Winter wheat—3 deep-plowed, 4 subsoiled.....	1923	2	.080	.082
S. L.....	9.....	Winter wheat—basin-listed.....	1923	1	.074	.079
Average.....					.082	.085
CONTINUOUS SMALL GRAIN—ALTERNATELY PLOWED AND DISKED						
S. L.....	5, 6.....	Winter wheat.....	1923	2	0.080	0.080
262, 264 <sup>1</sup> .....	A.....	Winter wheat; oats or barley.....	1923	2	.084	.086
Average.....					.082	.083
CONTINUOUS SMALL GRAIN—DISKED						
S. L.....	7, 8.....	Winter wheat.....	1923	2	0.088	0.088
CONTINUOUS SMALL GRAIN—BASIN-LISTED (MANURED)						
S. L.....	10.....	Winter wheat (manured).....	1923	1	0.081	0.084
ALTERNATE SMALL GRAIN AND FALLOW						
267.....	A.....	Winter wheat, fallow.....	1919	1	0.078	0.078
ALTERNATE SMALL GRAIN AND FALLOW (MANURED)						
268, 269.....	A.....	Winter wheat, fallow (manured).....	1919	2	0.085	0.080

## CONTINUOUS ROW CROP

M. C. ....	A-B .....	Kafir—plowed .....	1916	2	0.059	0.078
M. C. ....	A-B .....	Peterita—plowed .....	1916	2	.058	.080
Average .....					.058	.079

## ALTERNATE ROW CROP AND FALLOW

M. C. ....	C-D .....	Kafir, fallow .....	1916	2	0.062	0.080
M. C. ....	C-D .....	Peterita, fallow .....	1916	2	.058	.084
397 .....	A .....	Cotton, fallow .....	1919	1	.064	.079
Average .....					.061	.081

## ALTERNATE ROW CROP AND FALLOW (MANURED)

398, 399 .....	A .....	Cotton, fallow (manured) .....	1919	2	0.064	0.075
----------------	---------	--------------------------------	------	---	-------	-------

## ALTERNATE SMALL GRAIN AND ROW CROP

260 <sup>1</sup> .....	A .....	Winter wheat, cotton .....	1923	1	0.081	0.084
------------------------	---------	----------------------------	------	---	-------	-------

## ALTERNATE SMALL GRAIN AND COWPEAS

265 .....	A .....	Winter wheat, cowpeas .....	1919	1	0.080	0.091
-----------	---------	-----------------------------	------	---	-------	-------

## ALTERNATE SMALL GRAIN AND COWPEAS (GREEN MANURE)

266 .....	A .....	Winter wheat, cowpeas (green manure) .....	1919	1	0.082	0.086
-----------	---------	--------------------------------------------	------	---	-------	-------

## ALTERNATE SMALL GRAIN (TOPDRESSED WITH MANURE), COWPEAS

364 .....	A .....	Winter wheat (topdressed with manure), cowpeas .....	1919	1	0.090	0.094
-----------	---------	------------------------------------------------------	------	---	-------	-------

## VIRGIN SOD

None .....		Native grasses .....		9	0.154	0.103
------------	--	----------------------	--	---	-------	-------

<sup>1</sup> The symbol "M. C." means "Methods of cropping." The symbol "S. L." means "Seedbed plots with winter wheat at Lawton."

<sup>2</sup> From 1919 to 1922, inclusive, rotation 262 was in alternate corn and wheat, and rotation 264 in alternate kafir and wheat.

<sup>3</sup> From 1919 to 1922, inclusive, rotation 260 was a rotation of wheat, and corn and cowpeas in alternate rows.



TABLE 43.—*Nitrogen and carbon content and carbon/nitrogen ratio of the soil under various rotations at Dalhart, Tex., 1947*

## CONTINUOUS ROW CROP

Rotation <sup>1</sup>	Plot	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—		Carbon at—		Ratio of carbon to nitrogen	
					0 to 6½ inches	6½ to 12 inches	0 to 6½ inches	6½ to 12 inches	0 to 6½ inches	6½ to 12 inches
M. C.-----	A-B-----	Corn (south field)—plowed-----	1908	2	<i>Percent</i> 0.050	<i>Percent</i> 0.052	<i>Percent</i> 0.53	<i>Percent</i> 0.52	10.7	10.0
M. C.-----	A-B-----	Corn (north field)—plowed-----	1914	2	.037	.051	.38	.48	10.3	9.5
M. C.-----	A-B-----	Kafir (south field)—plowed-----	1908	2	.042	.048	.48	.48	11.3	10.2
M. C.-----	A-B-----	Milo (south field)—plowed-----	1908	2	.042	.052	.48	.52	11.2	10.2
Average-----	-----	-----	-----	-----	.043	.051	.46	.50	10.9	10.0

## ALTERNATE ROW CROP AND FALLOW

M. C.-----	C-D-----	Corn, fallow—south field-----	1908	2	0.046	0.051	0.48	0.48	10.5	9.4
M. C.-----	C-D-----	Corn, fallow—north field-----	1914	2	.037	.052	.34	.44	9.4	8.4
M. C.-----	C-D-----	Kafir, fallow—south field-----	1908	2	.038	.042	.42	.45	10.8	10.6
M. C.-----	C-D-----	Milo, fallow—south field-----	1908	2	.041	.050	.44	.46	10.9	9.3
Average-----	-----	-----	-----	-----	.040	.049	.42	.46	10.4	9.4

## ROW CROP, COWPEAS, SMALL GRAIN

88-----	A-C-----	Corn, cowpeas, winter rye—west field-----	1914	3	0.046	0.047	0.45	0.45	9.9	9.5
---------	----------	-------------------------------------------	------	---	-------	-------	------	------	-----	-----

## ROW CROP (TOPDRESSED WITH MANURE), COWPEAS, SMALL GRAIN

89-----	A-C-----	Corn (topdressed with manure), cowpeas, winter rye—west field.	1914	3	0.052	0.049	0.54	0.49	10.4	10.0
---------	----------	----------------------------------------------------------------	------	---	-------	-------	------	------	------	------

## VIRGIN SOD

None-----	-----	Native grasses-----	-----	9	0.067	0.059	0.72	0.60	10.9	10.2
-----------	-------	---------------------	-------	---	-------	-------	------	------	------	------

<sup>1</sup> The symbol "M. C." means "Methods of cropping."

TABLE 44.—*Nitrogen percentage of the soil under various rotations at Big Spring, Tex., 1947*

## CONTINUOUS SMALL GRAIN

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—	
					0 to 6 inches	6 to 12 inches
M. C.-----	A-B-----	Winter wheat—plowed-----	1916	2	Percent 0.051	Percent 0.050

## ALTERNATE SMALL GRAIN AND FALLOW

M. C.-----	C-D-----	Winter wheat, fallow-----	1916	2	0.060	0.054
------------	----------	---------------------------	------	---	-------	-------

## CONTINUOUS SMALL CROP

M. C.-----	A-B-----	Cotton—plowed-----	1916	2	0.031	0.044
M. C.-----	A-B-----	Milo—plowed-----	1916	2	.033	.046
Average-----					.032	.045

## ALTERNATE ROW CROP AND FALLOW

M. C.-----	C-D-----	Cotton, fallow-----	1916	2	0.030	0.043
M. C.-----	C-D-----	Milo, fallow-----	1916	2	.037	.052
Average-----					.034	.047

## ROW CROP (TOPDRESSED WITH MANURE), COWPEAS

301-----	A-B-----	Milo topdressed with manure, cowpeas-----	1920	2	0.064	0.050
----------	----------	-------------------------------------------	------	---	-------	-------

## ROW CROP, COWPEAS, SMALL GRAIN

166-----	A-C-----	Milo, cowpeas, winter wheat-----	1919	3	0.042	0.044
----------	----------	----------------------------------	------	---	-------	-------

See footnote at end of table.

TABLE 44.—*Nitrogen percentage of the soil under various rotations at Big Spring, Tex., 1947*—Continued

ROW CROP, FALLOW, FALLOW, FALLOW

Rotation <sup>1</sup>	Plots	Crops and tillage treatments	Year started	Number of plots	Nitrogen at—	
					0 to 6 inches	6 to 12 inches
570.....	A-D.....	Milo, fallow, fallow, fallow.....	1916	4	Percent 0.041	Percent 0.046
VIRGIN SOD						
None.....	.....	Native grasses.....	.....	9	0.060	0.050

<sup>1</sup> The symbol "M. C." means "Methods of cropping."

TABLE 45.—Percentage of total nitrogen in the 0- to 6-inch depth of soil from different cropping treatments at 9 locations in the Great Plains, 1950; and parts per million of nitrate-nitrogen produced by these soils during a 6-week incubation period

PREVIOUS CROP—ROW CROP											
Cropping and tillage treatment	Soil nitrogen and unit	Total nitrogen and nitrate-nitrogen in soil at—									Average at 7 locations
		Havre	Huntley	Sheridan	Archer	Newell	North Platte	Colby	Garden City	Dalhart	
Continuously cropped	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	0.075 21.3	0.076 10.7	0.100 41.3	-----	0.101 14.1	0.074 22.6	0.071 16.1	0.064 59.3	0.044 11.3	0.076 24.9
Do	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.074 23.8	.067 10.2	.097 33.3	-----	.100 15.3	.072 21.7	.067 19.0	.065 28.2	.042 12.5	.073 20.3
Alternately cropped and fallowed, cropped plot	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.070 28.3	.066 16.5	.100 40.6	-----	.082 11.3	.074 20.5	.063 11.4	.059 30.1	.043 14.0	.069 21.7
Alternately cropped and fallowed, fallowed plot	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.073 24.2	.064 7.8	.086 35.1	-----	.091 14.7	-----	.068 9.9	.070 62.0	.038 10.3	.070 23.4
Rotation of crops	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.082 33.7	.099 23.2	.126 40.4	.074 31.8	.102 18.4	.082 31.7	.084 37.9	.058 52.9	.042 18.4	.085 32.1
PREVIOUS CROP—SMALL GRAIN											
Continuously cropped	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	0.088 33.1	0.088 19.2	0.112 42.2	0.078 45.2	0.117 27.0	0.096 36.4	0.119 44.4	0.098 85.5	0.036 20.9	0.094 38.9
Do	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.092 28.3	.080 21.3	.110 52.6	.081 52.1	.112 19.3	.090 31.0	.108 45.0	.087 44.1	.042 23.0	.090 33.4
Alternately cropped and fallowed, cropped plot	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.083 21.2	.078 17.1	.105 48.3	.083 45.1	.106 19.9	.096 31.8	.099 33.9	.083 51.7	.045 22.8	.086 30.7
Alternately cropped and fallowed, fallowed plot	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.091 20.5	.078 16.7	.091 41.1	.091 47.8	.098 19.3	-----	.100 38.9	.082 66.5	.046 28.3	.084 33.0
Rotation of crops	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	.084 32.3	.100 19.9	.118 39.7	.070 37.2	.104 19.8	.078 25.1	.090 34.7	.065 95.8	.042 20.8	.086 37.6
VIRGIN SOD											
Native grasses	Total nitrogen (percent)----- {Nitrate-nitrogen (p. p. m.)-----	0.121 39.7	----- -----	0.171 73.6	0.116 60.1	<sup>1</sup> 0.166 <sup>1</sup> 49.3	<sup>1</sup> 0.176 <sup>1</sup> 58.8	0.153 42.3	----- -----	0.068 25.5	0.139 49.9

<sup>1</sup> Average of 2 samples.

TABLE 46.—Percentage of total nitrogen in 0- to 6-inch depth of soil from rotation plots at 4 locations in the Great Plains, 1950; and parts per million of nitrate-nitrogen produced by the soil during a 6-week incubation period

MOCCASIN, MONT.

Rotation <sup>1</sup>	Crops <sup>2</sup> and tillage treatments	When previous crop was—					
		Row crop		Small grain		Native grasses	
		Total nitrogen	Nitrate-nitrogen	Total nitrogen	Nitrate-nitrogen	Total nitrogen	Nitrate-nitrogen
		Percent	P. p. m.	Percent	P. p. m.	Percent	P. p. m.
49.-----	Corn, spring wheat.....	0.210	33.3	0.204	35.3	-----	-----
1.-----	Corn, spring wheat, oats.....	.196	36.6	.191	35.4	-----	-----
18.-----	Corn, oats, fallow, spring wheat.....	.224	38.4	.219	39.1	-----	-----
68.-----	Corn (manured), spring wheat, oats.....	.241	53.2	.225	49.0	-----	-----
15.-----	Corn, oats, rye (green manure), spring wheat.....	.206	42.5	.208	36.7	-----	-----
32.-----	Corn, oats, sweet clover (green manure), spring wheat.....	.204	47.1	.201	43.5	-----	-----
41.-----	Corn, spring wheat, oats, 3 plots crested wheat.....	.242	<sup>3</sup> 53.3	.228	<sup>4</sup> 42.4	-----	-----
42.-----	Corn, spring wheat, oats, 3 plots alfalfa.....	.270	<sup>3</sup> 64.3	.222	<sup>4</sup> 44.2	-----	-----
64.-----	Winter wheat, oats, rye (green manure).....	-----	-----	.180	38.1	-----	-----
64.-----	Winter wheat, oats, rye (green manure).....	-----	-----	.196	40.3	-----	-----
5.-----	Spring wheat, oats, fallow.....	-----	-----	.192	29.6	-----	-----
5.-----	Spring wheat, oats, fallow.....	-----	-----	.202	34.9	-----	-----
M. C.-----	Continuous corn or spring wheat.....	.179	43.2	.226	53.0	-----	-----
M. C.-----	do.....	.156	27.2	.194	39.5	-----	-----
M. C.-----	Alternate corn or spring wheat and fallow.....	.136	22.3	.197	31.1	-----	-----
M. C.-----	Alternate corn, or spring wheat and fallow.....	.142	<sup>5</sup> 23.4	.192	<sup>3</sup> 35.8	-----	-----
None-----	Virgin sod.....	-----	-----	-----	-----	0.284	44.1

ARKON, COLO.

252	Corn, winter wheat	0.077	32.0	0.085	31.7		
3	Corn, spring wheat, oats	.087	26.8	.091	40.0		
28	Corn, oats, fallow, winter wheat	.083	32.9	.082	30.5		
251	Corn-manured, winter wheat	.104	45.7	.103	46.7		
51	Corn, barley, rye (green manure), winter wheat	.079	32.8	.081	31.5		
92	Corn, barley, peas (green manure), winter wheat	.086	29.6	.096	35.5		
41	Corn, spring wheat, oats, 3 plots grass	.085	26.0	.082	31.6		
42	Corn, spring wheat, oats, 3 plots alfalfa	.086	27.2	.089	29.8		
5	Spring wheat, oats, fallow			.086	37.2		
5	Spring wheat, oats, fallow			.089	40.1		
268	Winter wheat, fallow (manured)			.092	35.0		
268	Winter wheat, fallow (manured)			.092	36.7		
M. C	Continuous corn or spring wheat	.066	27.1	.092	39.9		
M. C	do	.063	24.3	.092	43.7		
M. C	Alternate corn or spring wheat and fallow	.057	24.2	.076	35.1		
M. C	Alternate corn or spring wheat and fallow	.057	18.1	.076	24.3		
None	Virgin sod					0.126	38.1

See footnotes at end of table.

TABLE 46.—Percentage of total nitrogen in 0- to 6-inch depth of soil from rotation plots at 4 locations in the Great Plains, 1950; and parts per million of nitrate-nitrogen produced by the soil during a 6-week incubation period—Continued

HAYS, KANS.

Rotation <sup>1</sup>	Crops <sup>2</sup> and tillage treatments	When previous crop was—					
		Row crop		Small grain		Native grasses	
		Total nitrogen	Nitrate-nitrogen	Total nitrogen	Nitrate-nitrogen	Total nitrogen	Nitrate-nitrogen
		Percent	P. p. m.	Percent	P. p. m.	Percent	P. p. m.
349 <sup>6</sup>	Kafir, winter wheat			0.107	47.7		
349 <sup>6</sup>	do			.100	50.0		
1 <sup>7</sup>	Corn, spring wheat, oats	0.107	33.2				
1 <sup>7</sup>	do	.100	26.5				
551	Kafir, fallow, winter wheat	.093	26.7	.104	41.4		
57	Corn, barley, fallow, winter wheat	.104	24.3	.117	33.6		
403	Corn, barley, winter wheat, winter wheat	.108	28.7	.110	48.5		
558	Kafir (6 tons manure), fallow, winter wheat	.118	35.5	.108	35.1		
560	Kafir (12 tons manure), fallow, winter wheat	.147	39.1	.129	40.7		
92 <sup>8</sup>	Milo, barley, fallow, winter wheat	.122	49.9	.115	36.7		
51 <sup>9</sup>	do	.119	54.0	.137	67.9		
141 <sup>10</sup>	Milo, fallow, winter wheat, 3 plots grass	.110	<sup>4</sup> 33.8	.141	<sup>3</sup> 66.0		
142 <sup>11</sup>	Milo, fallow, winter wheat, 3 plots alfalfa	.110	<sup>4</sup> 36.3	.126	<sup>3</sup> 39.9		
570	Winter wheat, fallow, fallow, fallow			.100	49.8		
570	Winter wheat, fallow, fallow, fallow			.100	<sup>3</sup> 48.9		
M. C.	Continuous kafir or spring wheat	.094	27.0	.149	54.1		
M. C.	do	.084	31.5	.136	59.1		
M. C.	Alternate kafir or spring wheat and fallow	.075	28.1	.125	58.5		
M. C.	Alternate kafir or spring wheat and fallow	.089	<sup>3</sup> 25.5	.113	<sup>3</sup> 44.1		
None	Virgin sod					0.181	44.4

## BIG SPRING, TEX.

236.....	Milo, cowpeas.....	0.028	7.5			
236.....	Milo, <u>cowpeas</u> .....	.030	8.7			
202.....	Milo, cotton, cowpeas.....	.026	10.1			
202.....	Milo, cotton, <u>cowpeas</u> .....	.026	8.6			
223.....	Milo, cowpeas, cotton, fallow.....	.032	10.1			
223.....	Milo, cowpeas, cotton, <u>fallow</u> .....	.028	9.1			
164.....	Winter wheat, winter wheat, cowpeas.....			0.047	17.7	
164.....	Winter wheat, winter wheat, <u>cowpeas</u> .....			.051	15.7	
205.....	Milo, cotton, cowpeas (green manure).....	.026	9.5			
205.....	Milo, cotton, cowpeas (green <u>manure</u> ).....	.027	8.9			
273.....	Milo, cowpeas, cotton, fallow (manured).....	.050	15.7			
273.....	Milo, cowpeas, cotton, fallow (manured).....	.041	16.4			
570.....	Milo, fallow, fallow, fallow.....	.032	8.7			
570.....	Milo, fallow, fallow, <u>fallow</u> .....	.030	<sup>a</sup> 9.0			
M. C.....	Continuous milo, or winter wheat.....	.023	9.7	.042	14.7	
M. C.....	do.....	.022	7.6	.045	14.8	
M. C.....	Alternate milo or winter wheat and fallow.....	.025	7.8	.045	15.6	
M. C.....	Alternate milo or winter wheat and <u>fallow</u> .....	.025	<sup>a</sup> 7.6	.045	<sup>a</sup> 12.9	
M. C.....	Continuous cotton.....	.024	9.0			
M. C.....	do.....	.026	8.5			
M. C.....	Alternate cotton and fallow.....	.026	8.1			
M. C.....	Alternate cotton and <u>fallow</u> .....	.028	<sup>a</sup> 7.9			
None.....	Virgin sod.....					0.058 23.8

<sup>1</sup> The symbol "M. C." means "Methods of cropping." Rotations which tend to exert similar effects on soil nitrogen are grouped for comparison.

<sup>2</sup> The underscored crop indicates the previous crop.

<sup>3</sup> Plot most recently broken from sod.

<sup>4</sup> Plot farthest removed from sod.

<sup>5</sup> Plots were in summer fallow prior to sampling.

<sup>6</sup> This rotation was in effect 1915-45. In 1946 the area was uniformly cropped to milo, in 1947 fallowed, and in 1948-50 uniformly cropped so winter wheat.

<sup>7</sup> This rotation was in effect 1906-45. The area was uniformly cropped to milo in 1946, fallowed in 1947, in winter wheat in 1948, and in milo 1949-50.

<sup>8</sup> The rotation as shown has been in effect since 1946. From 1906-45, the rotation was corn, barley, cowpeas plowed-under for green manure, winter wheat.

<sup>9</sup> The rotation as shown has been in effect since 1946. From 1906-45, the rotation was corn, barley, winter rye plowed-under for green manure, winter wheat.

<sup>10</sup> Rotation of milo, fallow, winter wheat, and 12-year-old stands of buffalograss since 1941. From 1906-40, the rotation was corn, winter wheat, oats, and 3-year-old stands of bromegrass.

<sup>11</sup> Similar to rotation 141, except that alfalfa was used instead of grass until 1949, at which time a mixture of blue and side-oats grama replaced the alfalfa.



TABLE 47.—Average precipitation, average actual yield per acre, and calculated yield per acre for the first and last years of period under different cropping treatments at 6 stations

MANDAN, N. DAK. (1915-43)

Crops and tillage treatments	Average precipitation <sup>1</sup>	Actual average yield <sup>2</sup>	Calculated yield <sup>3</sup>	
			First year	Last year
<b>Corn (grain):</b>	<i>Inches</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	15.31	27.7	34.7	25.2
Alternate fallow.....	30.71	29.2	37.9	26.4
Rotation without manure.....	16.61	25.9	29.7	25.5
Rotation with manure.....	16.61	24.8	30.6	21.4
<b>Corn (stover):</b>		<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Continuous.....	15.31	2,030	2,720	1,570
Alternate fallow.....	30.71	1,990	2,790	1,470
Rotation without manure.....	16.61	1,780	2,080	1,620
Rotation with manure.....	16.61	2,780	2,980	2,770
<b>Wheat (grain):</b>		<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	15.26	13.7	12.3	16.5
Alternate fallow.....	30.65	20.9	18.6	24.5
Rotation without manure.....	13.96	15.2	17.6	15.3
Rotation with manure.....	13.96	17.8	16.4	24.0

DICKINSON, N. DAK. (1908-47)

<b>Corn (grain):</b>	<i>Inches</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	15.98	19.1	30.6	21.2
Alternate fallow.....	31.76	22.1	34.7	24.1
Rotation without manure.....	17.67	14.0	22.3	18.0
Rotation with manure.....	17.67	16.5	23.6	23.2
<b>Corn (stover):</b>		<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Continuous.....	15.98	3,230	4,100	3,110
Alternate fallow.....	31.76	3,530	4,010	3,620
Rotation without manure.....	17.67	3,000	3,980	2,920
Rotation with manure.....	17.67	4,150	4,910	4,740
<b>Wheat (grain):</b>		<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	15.96	11.4	15.3	11.4
Alternate fallow.....	31.79	19.8	23.3	19.1
Rotation without manure.....	14.27	13.5	18.4	12.5
Rotation with manure.....	14.27	17.7	21.3	20.2

HAVRE, MONT. (1917-47)

<b>Corn (grain):</b>	<i>Inches</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	11.68	12.2	16.2	15.6
Alternate fallow.....	23.60	18.3	23.2	24.3
Rotation without manure.....	12.82	10.5	13.6	17.8
Rotation with manure.....	12.82	9.9	14.6	13.4
<b>Corn (stover):</b>		<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Continuous.....	11.68	2,080	3,010	1,250
Alternate fallow.....	23.60	2,590	3,510	2,910
Rotation without manure.....	12.82	1,910	2,460	1,450
Rotation with manure.....	12.82	2,180	2,830	1,670
<b>Wheat (grain):</b>		<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	11.63	8.1	8.3	8.0
Alternate fallow.....	23.58	16.3	11.8	19.4
Rotation without manure.....	10.48	11.9	12.5	10.9
Rotation with manure.....	10.48	12.5	14.9	9.7

See footnotes at end of table.

# NITROGEN AND CARBON CHANGES IN GREAT PLAINS SOILS 111

**TABLE 47.—Average precipitation, average actual yield per acre, and calculated yield per acre for the first and last years of period under different cropping treatments at 6 stations—Continued**

## SHERIDAN, WYO. (1918-47)

Crops and tillage treatments	Average precipitation <sup>1</sup>	Actual average yield <sup>2</sup>	Calculated yield <sup>3</sup>	
			First year	Last year
<b>Corn (grain):</b>	<i>Inches</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	16.21	16.9	80.3	10.6
Alternate fallow.....	32.28	19.3	28.2	15.0
Rotation without manure.....	16.98	14.5	25.8	7.5
Rotation with manure.....	16.98	14.2	24.2	7.9
<b>Corn (stover):</b>		<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Continuous.....	16.21	1,160	1,810	620
Alternate fallow.....	32.28	1,150	1,580	810
Rotation without manure.....	16.98	1,220	1,840	720
Rotation with manure.....	16.98	1,560	2,140	1,110
<b>Wheat (grain):</b>		<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	16.21	12.6	16.6	10.2
Alternate fallow.....	32.28	24.4	25.3	24.2
Rotation without manure.....	15.44	17.9	20.4	17.8
Rotation with manure.....	15.44	20.5	20.4	22.4

## ARCHER, WYO. (1914-45)

<b>Corn (grain):</b>	<i>Inches</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	14.48	13.6	19.8	11.4
Alternate fallow.....	28.95	15.7	18.6	15.8
Rotation without manure.....	17.63	13.0	19.3	11.6
Rotation with manure.....	17.63	11.3	15.1	11.7
<b>Corn (stover):</b>		<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Continuous.....	14.48	1,390	2,110	770
Alternate fallow.....	28.95	1,470	1,940	1,080
Rotation without manure.....	17.63	1,470	2,280	780
Rotation with manure.....	17.63	1,490	2,100	990
<b>Wheat (grain):</b>		<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	14.51	7.7	10.2	5.9
Alternate fallow.....	29.13	13.1	13.1	13.7
Rotation without manure.....	11.36	10.3	13.5	8.2
Rotation with manure.....	11.36	10.2	14.0	7.5

## HAYS, KANS. (1916-46)

<b>Kafir (grain):</b>	<i>Inches</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	22.02	15.3	21.5	13.7
Alternate fallow.....	44.48	25.7	37.3	27.1
Rotation without manure.....	29.93	20.4	27.9	23.1
Rotation with manure.....	29.93	20.8	24.5	26.3
<b>Kafir (stover):</b>		<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
Continuous.....	22.02	3,940	5,210	2,610
Alternate fallow.....	44.48	5,780	7,130	4,180
Rotation without manure.....	29.93	4,530	5,020	3,890
Rotation with manure.....	29.93	4,800	4,850	4,570
<b>Wheat (grain):</b>		<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>
Continuous.....	22.21	14.2	19.0	14.5
Alternate fallow.....	44.71	24.1	27.0	22.2
Rotation without manure.....	36.76	22.0	24.6	22.5
Rotation with manure.....	36.76	19.9	23.8	17.5

<sup>1</sup> Precipitation from harvesttime of one crop to harvesttime of next crop.

<sup>2</sup> Years when hail damage occurred were omitted.

<sup>3</sup> Calculated from regression formulas.